IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Serial No. : 09/925,059
Applicants : Zhang, Evan
Filed : August 08, 2001
Title : IMAGE INTENSIFIER AND LWIR FUSION COMBINATION SYSTEM
Docket No. : ZZZ 033 PA
Examiner : Lee, Shun
Art Unit : 2878
Confirm No. : 2617

Commissioner for Patents
Washington, D.C. 20231

Sir:

DECLARATION OF PRIOR INVENTION IN THE UNITED STATES TO OVERCOME CITED PATENT (37 C.F.R. § 1.131)

I, Evan Zhang, declare and state as follows that:

1. I am the inventor of the invention entitled IMAGE INTENSIFIER AND LWIR FUSION COMBINATION SYSTEM, disclosed and claimed in U.S. Patent Application Serial No. 09/925,059 (hereinafter the '059 application), filed August 08, 2001.

2. In a non-final Office Action dated January 19, 2006, claims 44, 45, 47 and 48 were rejected under 35 U.S.C. §102(e) as being anticipated by the '799 patent. Claims 46 and 49 were rejected under 35 U.S.C. §103(a) as being obvious in view of the '799 patent. Further, claims 50 and 51 were rejected under 35 U.S.C. §103(a) as being obvious over the '799 patent in view of U.S. Patent 6,335,526 (hereinafter the '526 patent). The '799 patent has a 35 U.S.C. § 102(e) prior art date of August 30, 2000.

3. As evidence to establish conception and reduction to practice of the claimed invention, the following are provided:

Attached as Exhibit A is a document entitled "Innovative Fusion Goggle System Design"; 8 pages including a cover sheet, pages 1-6; 19. This report was authored by me before August 30, 2000, and represents a proposal prepared under solicitation USZA22-00-R-0021.

Attached as Exhibit B is a document entitled "Low Cost Night Vision System for High Speed Vessel Operations"; 23 pages including pages 3-25. This report was authored by me before August 30, 2000, and represents a proposal prepared under topic 00-CG1.

Attached as Exhibit C is a document entitled "Development of Universal, Inexpensive Optics for Uncooled Infrared Commercial and Military Applciations"; 11 pages including pages 3-12 and 21. This report was authored by me before August 30, 2000, and represents a proposal prepared under topic A00-149.

Attached as Exhibit D is a document entitled "sensor suite for UAV"; 3 pages including Pages 7-9. This report was authored by me in April of 2001, and represents a white paper for the electronic and optical fusion of images.

Attached as Exhibit E is a document entitled "Low-cost Dual-mode (Visible/Infrared) Imager"; 3 pages including pages 1-2; 17. The Abstract of this report was signed by me on August 02, 2001, and represents a proposal prepared under topic N01-179. Page number 17 includes as Figure 4, a photograph of a handheld VIS and LIR sensor fusion system with a common beam splitter.

Attached as Exhibit F is a single page letter to the Army SBIR Office dated July 28, 2000.

4. Evidence to establish a conception and reduction to practice date prior to August 30, 2000 is as follows:

Evidence of conception and reduction to practice of the subject matter of claim 44 prior to August 30, 2000 can be found in Exhibit F, which illustrates a schematic representation of the features in claim 44, as well as a photograph of a prototype actually built by me prior to August 08, 2000. As seen in Fig. 1, a sensor fusion system comprises a common aperture, a beam splitter arranged to receive target radiation passed through the common aperture and to split the target radiation into a first spectral band and a second spectral band, a first sensor (I^2 tube) arranged to receive radiation split into the first spectral band and a second sensor (LWIR) arranged to receive radiation split into the second spectral band. The first and second sensors share a common aperture such that parallax between the first and second sensors is substantially eliminated. Further, the output of the first and second sensors is optically fused by the beam combiner. Still further, the optical aperture is aligned with the eye viewer along a common optical axis to substantially eliminate parallax between the sensor fusion system and the viewer.

Further, the subject matter of claim 44 was reduced to practice prior to August 30, 2000, as evidenced by Fig. 2, which shows a photograph of a working embodiment of Fig. 1 of Exhibit F.

Evidence of conception of the subject matter of claims 44 can further be found in Exhibit B, for example, on page 22 Figs. 6 and 7, as well as the corresponding descriptions on pages 10-11. As seen in Fig. 7 on page 22, a sensor fusion system comprises a common aperture, a beam splitter BS_1 arranged to receive target radiation passed through the common aperture and to split the target radiation into a first spectral band and a second spectral band, a first sensor (I^2 tube) arranged to receive radiation split into the first spectral band and a second sensor (MTB LCD) arranged to receive radiation split into the second spectral band. The first and second sensors share a common aperture such that parallax between the first and second sensors is substantially eliminated. Further, the output of the first and second sensors is optically fused by the beam combiner BS_2 via the I^2 output and the LCD from the MTB. Still further, the optical

aperture is aligned with the eye viewer along a common optical axis to substantially eliminate parallax between the sensor fusion system and the viewer.

Evidence of conception and reduction to practice of the subject matter of claims 48 can be found in Exhibit F Figs. 1 and 2 as described more fully above. See also, Exhibit A, pages 4-6 under the section "1. Fusion System" and Figs. 1 and 3b on page 19. See also, Exhibit B on page 10 under the heading "Common Objective Lens Design" and in Figs. 4, 6, 7 on page 20-22.

5. Evidence to establish conception and reduction to practice date prior to July, 2000 is as follows:

Evidence of conception of the subject matter of claims 47 can be found for example, in Exhibit A, pages 4-6 under the section "1. Fusion System" and Figs. 1 and 3a on page 19.

Evidence of conception of the subject matter of claims 50 can be found in Exhibit A, pages 4-6 under the section "1. Fusion System" and Figs. 1 and 3b on page 19. See also, Exhibit B on page 10 under the heading "Common Objective Lens Design" and in Figs. 4, 6, 7 on page 20-22.

Evidence of conception of the subject matter of claims 51 can be found in Exhibit A, pages 4-6 under the section "1. Fusion System" and Figs. 1 and 3b on page 19. See also, Exhibit B on page 10 under the heading "Common Objective Lens Design" and in Figs. 4, 6, 7 on page 20-22.

Evidence of reduction to practice of the subject matter of claims 47, 50 and 51 can be seen in the photograph shown in Exhibit E, Fig. 4 on the third page of the Exhibit (numbered page 17). The prototype shown in Fig. 4 was reduced to practice in July 2001.

6. Evidence to establish conception prior to August 30, 2000 is as follows:

Evidence of conception of the subject matter of claims 45 can be found in Exhibit A, pages 4-6 under the section "1. Fusion System" and Figs. 1 and 3b on page 19. See also, Exhibit B on page 10 under the heading "Common Objective Lens Design" and in Figs. 4, 6, 7 on page 20-22.

Evidence of conception of the subject matter of claims 46 can be found in Exhibit A, pages 4-6 under the section "1. Fusion System" and Figs. 1 and 3b on page 19. See also, Exhibit B on page 10 under the heading "Common Objective Lens Design" and in Figs. 4, 6, 7 on page 20-22.

Evidence of conception of the subject matter of claims 49 can be found in Exhibit A, pages 4-6 under the section "1. Fusion System" and Figs. 1 and 3b on page 19. See also, Exhibit B on page 10 under the heading "Common Objective Lens Design" and in Figs. 4, 6, 7 on page 20-22.

7. With respect to claims 45-47; 49-51, I believe that I and my patent attorneys were diligent just prior to the August 30, 2000 filing date of the '799 patent until July 2001. Further, with respect to claims 45, 46 and 49, I believe that I and my patent attorneys were diligent just prior to the August 30, 2000 filing date of the '799 patent until the filing of our application on August 8, 2001.

8. As demonstrated in Exhibit D, in July 2000, I submitted a proposal under the topic of A00-149 "Development of Universal Inexpensive Optics for Uncooled Infrared Commercial and Military Applications". As shown in Fig. 5 on page 21, a common refractive objective lens was designed which was believed to be suitable for optical, digital or optical and digital fusion. In order to perform suitable testing on the proposed lens designs, it was necessary to have the BST equipment manufacturer (Raytheon) remove the 8-12μ filter in the front of the focal plane array.

Upon receiving a suitable FPA from the manufacturer around January 2001, experiments and demonstrations were performed in our optical laboratory. However, the sensitivities of the BST in the NIR and MIR bands were insufficient to provide satisfactory results and continued design, testing and experimentation were required.

9. Exhibit D further sets out on pages 11 and 12, a detailed step by step time table that shows the work required over at least a seven month period including the time frame from August 2000 through February 2001, to test and determine the feasibility of the lens designs described at length in Exhibit C.

10. In at least March and April of 2001, work was performed to design and test a common optical aperture (common beam splitter) for the electronic or optic as seen in Fig. 1 on page 9 of the white paper of Exhibit D. Continued efforts to reduce the common beam splitter to practice were carried out in May and June of 2001.

9. In July-August 2001, I performed experiments and completed work necessary to address the problems associated with blurring overlapped images by using a video switch to combine VS and IR images together as evidenced by Exhibit F.

11. Further, I began working with my patent firm to draft a regular utility application in January 2001. A first draft of the patent application was reviewed and revised by me in April 2001. A second draft was reviewed and revised by me in June 2001 and a third draft was reviewed and revised by me in July of 2001. The application was filed on August 8, 2001.

As a person signing below:

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are

punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full name of inventor: Evan Zhang

Inventor's signature: E. W. Zhang

Date: 5/19/06 Country of Citizenship: USA

Post Office Address: 3915 Germany Lane
Beavercreek, OH 45431, USA

EXHIBIT A

/ in 2000

USZA22-00-R-0021

Fact 2

Innovative Fusion Goggle System Design

Principal Investigator: Evan Zhang, Ph. D, Zybron, Inc.
Consultants: Chuan Li, Ph. D, Boeing, Inc.
Mike Newell, Ph. D, Optics 1, Inc.
Gary Palmer, Ph. D, ITT, Inc.
Jene Horn, Ph. D, STS, Inc.

Innovative Fusion Goggle System Design

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Gary Palmer, Ph. D, ITT, Inc.
Jene Horn, Ph. D, STS, Inc.

I. Summary

Based on our three Goggle Fusion Systems with two separated heads developed under the phase-I contract supported by SOCOM, in this proposal, a common head FGS is designed. It uses a common optical aperture to remove the parallax between the I^2 and IR channels to get a clear fused image. Three common optical apertures are proposed. The most compact one is the common transmissive objective lens. Let the I^2 and IR channels share the front lens made by ZnSE having high transmittance from 0.6 to 12 μ and the beam splitter then use different materials to design the I^2 and IR sub-objective lenses independently, we are able to correct the aberrations for I^2 in the waveband from 0.6 to 0.9 μ and for IR in the waveband from 8 to 12 μ. It is probably the first time in the history that a good common objective lens for both channels has been designed. It has large field of view (40°) and fast speed (f/1.25 for I^2, and f/1.0 for IR). It has high-resolution of 40 lp/mm with good MTF for I^2, and medium-resolution of 10 lp/mm with good MTF for IR. By sending the video signal from the IR channel to a buffer and scaling the format and linearly inserting data between pixels, we are able to get the same format and resolution as the I^2 on the LCD. This IR image can be fused with the I^2 image optically and sent to user's eye through the same eyepiece. If we fuse this IR image with the I^2CCD image electronically, we can precisely do pixel by pixel image addition, subtraction, convolution, and so on. Otherwise, we never can do true image fusion, we only can get a blurred overlapping image (instead of two eyes of a person, the fused image will have four eyes).

By using 320x240/25μ UFPA without TE cooler produced by Boeing or Raytheon for IR and one Altera chip for all digital signal processing, and using 16-mm I^2 tube of Gen-IV produced by ITT and our simplified optics and electronics, we are able to dramatically reduce the size, weight, and power for both systems. Therefore, a one-head FGS with a total weight of 1 pound and a total volume of 55.25 cubic inches including the waterproof enclosure with thick foam inset cut between the FGS and enclosure, and a battery compartment with 2 "AA" Lithium batteries lasting for 4 hours, has been designed. Since the FGS is a stand along unit, it can be used as a handheld device. Of course, the FGS can be mounted on the front of the military helmet with spring-loaded or dovetail mount having up-down, forward-back, and tilt adjustments. A 1-pound and 49.5 inch^3 waterproof battery pack with 4 "A" size Lithium batteries and 1-2 LCD electronic boards will be mounted on the rear of the helmet to get perfect weight balance. This extra power supply can last for 12 hours and will be connected with the FGS by cable

underneath the helmet. In addition, our FGS has the seeing through fog capability. In this proposal, we also give 4 useful optional attachment designs.

Obviously, this compact and ruggedized FGS can be used in adverse environment conditions and can satisfy all solicitation requirements. We will deliver and demonstrate the first FGS prototype of two heads 4 months after the contract award, the second FGS prototype of one head 8 months after the contract award, and the third FGS prototype of one head 10 months after the contract award.

II. Introduction

Zybron, a minority firm with 8(a) status, was formed 12 years ago. Zybron had got 3 phase-I and 3 phase-II contracts from the Air Force, and 2 phase-I contracts from the US Special Operations Forces. Under these contracts, Zybron had developed a helmet mounted uncooled infrared imaging system for fire fighting (see Fig.1) and 3 IR and I^2 goggle fusion systems for military applications (see Figs 2, 3 and 4). The Air Force had released a special news nation wide for Zybron's innovative IR sensor and fusion goggle developments and Zybron had made 5 successful fire fighting demonstrations in USA and overseas using above sensors (see Attachments 1, 2 and 3). Zybron was the only small business in Ohio obtained the SBIR Tibbetts award from the US government in 2,000 (see attachment 4), and Dr. Evan Zhang got two Ph. Ds (one in Sensor, one in Optical Electronics), he is very experienced in the IR and night vision goggle designs. Therefore, Zybron is well qualified as the principal investigator of this proposal to do the overall Fusion Goggle System (FGS) design. Other 4 well known companies will join the team as consultants. Boeing is the manufacturer of the Uncooled Focal Plane Array (UFPA) and very experienced in the detector and its related opto-electronics designs. Optics 1 is the manufacturer of the Liquid Crystal Display (LCD) with stereoscopic effect and has extensive knowledge in the optical system design. ITT is the manufacturer of the Gen-III and Gen-IV Image Intensifier (I^2) and very familiar with the night vision goggle interface. Specialized Technical Services (STS), Inc. is the manufacturer of night vision goggles and one of the pioneers of the fusion goggle development. As a neighbor in the same town, STS had cooperated with Zybron in several research areas for many years. By combining the expertise from above firms, not only a very innovative FGS can be design quickly and three prototype can be delivered to SOF within 10 months, but also the manufacturing and testing capabilities in the future will be guaranteed.

Actually, under the SBIR phase-I contract with SOF (#USZA 22-00-P-0029), Zybron has developed 3 FGS prototypes (see Figs 2, 3 and 4) and can deliver them to SOF right now. These prototypes can satisfy almost all requirements given by this solicitation. The prototype of Figure 2 fused the IR image from LCD into the I^2 goggle optically thus the high resolution of the I^2 can be kept. The prototype of Figure 3 fused the IR image to the left eye and the I^2 image after digitizing to the right eye electronically; open one eye, see one image; open two eyes, see both images overlapping together. The prototype of Figure 4 fused the LLL CCD image and IR image to the LCD alternatively using optical or electronic time-share method, both images were clearly overlapped together. These 3 prototype designs are in patent pending. We strongly suggest SOF to

use our phase-I result for this project. But we will deliver not only the two-head but the one-head FGS to SOF. Obviously, to let our team design and manufacture the FGS will only involve a minimal risk. However, Zybron is a small business with 8(a) status, we welcome SOF to arrange other big companies teaming up with Zybron to manufacture our current and proposed Fusion Goggle Systems if our proposal is acceptable. Actually, ITT has already signed the optional agreement to license our FGS technology (see attachment 5), and the Navy Chief Technology Office will give extra fund to Zybron for technology transition if we can get the award.

III. The innovative points of our proposal

(a) Instead of using current UFPA with 320 x 240 / 50 μ format, the next generation UFPAs of Microbolometer (MBT) or Silicon bolometer with 320 x 240 / 25 μ format will be used (Boeing has produced the 320 x 240 / 25 μ microbolometer). Because the size of the UFPA will be reduced to ¼ of the old format, the IR radiation intensity received by the same optics will be increased 4 times and the detecting distance can be increased twice. If keeping the same detecting distance, the size of the optics can be reduced to half. Because of the small format, accordingly, the sizes, weights and costs of the optics, calibration flag, electronic boards, display, mechanical interfaces, cases, and batteries can be dramatically reduced. We also will use 16-mm I^2 tube of Gen-IV (ITT has produced this kind tube) and simplify the I^2 goggle design, thus its weight and size also can be dramatically reduced. In addition, our innovative circuit design will eliminate the TE cooler to largely reduce the power consumption. Therefore, the total weight and size of the FGS can be reduced to 2/3 of the original limitation given by this solicitation, and two attached "AA" size Lithium batteries can operate the FGS for 4 hours. The battery pack with extra four "A" size Lithium batteries can operate the FGS for 12 hours.

(b) There are several parallaxes in the FGS. The first parallax is that the IR camera, display and human eye do not lie in the same line of sight. The second parallax is that the micro channel plate of I^2, LCD (if digitizing the I^2 image), and human eye do not lie in the same line of sight. The third parallax is that the IR system and I^2 system do not have a common optical aperture. The third parallax is the most serious problem. It prevents the IR image overlapping on the I^2 image correctly thus it will produce a blurred combination image. In this proposal, by aligning the optical axis of the camera, display and eye, we are able to eliminate the first and second parallaxes. By designing a common optical aperture for both IR and I^2 systems, we are able to remove the third parallax. The elimination of these parallaxes will not only be very helpful for doctor to do the surgery in the dark field during the war (light is not allowed), otherwise his knife would cut a wrong tissue, but also will be very important to do correct pixel by pixel data fusion for image addition, subtraction, convolution, etc. Without using common optical aperture, we never can get a clearly fused image.

(c) From the analysis of optical principle, there are only 3 common aperture configurations, i.e., common transmissive objective lens, common reflective objective lens, and common beam splitter. We have designed and patented all these 3 common optical apertures. will be

(d) The common transmissive objective lens approach is the best approach because of its very compact design for FGS. However to design an objective lens for the I^2 in 0.6 – 0.9 μ and the IR in 8 – 12 μ is very difficult and nobody had reached this goal before. By using ZnSe with high transmittance from 0.6 to 12 μ (see Fig. 5) as the first piece of the common objective lens and using different materials for the rest of the lens for I^2 and IR after inserting a beam splitter, we have designed and patented the first common transmissive objective lens in the history for the FGS.

(e) Not only natural fog will block the visions of I^2 and IR, enemy also will release artificial fog. Seeing through fog by FGS is an unsolved problem. By choosing proper eye safe laser diode and polarization filter, we are able to let the FGS penetrate fog and other scattering particles (see Fig. 6).

(f) In addition to the innovative FGS design satisfying the requirements of the solicitation, 4 additional designs are also given: wireless video and audio link between the front soldier and rear commander, hand free voice activated switching, pseudo-color representation of B&W IR and I^2 images, and automatic target recognition.

Now let us give the detailed innovative FGS design one item by one item that will satisfy all of the system specifications mentioned below.

IV. Fusion Goggle System Design

A. System Characteristics

1. Fusion System

The goal of this effort is is to design a FGS to contain all of the electronics within the goggle assembly with power supplied by a conformal helmet mounted battery assembly mounted on the rear of the helmet.

In order to reach this goal, the most important task is to design the I^2 and IR fusion system. As shown in Figures 2, 3 and 4, in the past we had designed 3 fusion systems with separated I^2 and IR heads thus they have small parallaxes. In this proposal we will design an innovative and unique common optical aperture that can completely remove the parallax for FGS. Although the common reflective objective lens using two mirrors has no color aberration for I^2 or IR, its narrow field of view (less than 10°) can not satisfy the 40° requirement of the solicitation thus we will not consider it. We will use common transmissive objective lens or beam splitter to design the FGS.

Three innovative approaches are proposed. In the first approach, a common front lens L_1 made by 2 pieces of ZnSe (see Fig. 5, it has good transmittance from 0.6 μ to 12 μ) will be used for both I^2 and IR channels. As shown in Fig.7, the beam splitter BS_1 will pass Visible (VIS) and Near Infrared Radiation (NIR) from 0.6 μ to 0.9 μ and reflect Long Infrared Radiation (LIR) from 8 μ to12 μ. For simplicity, on the diagram we only show an infinite target on the optical axis (actually the objective lens has 40° field of view). The VIS and NIR will be imaged by L_1 and its relay lens L_4 made by normal glasses that can further correct the aberrations and get high resolution image on the I^2 tube. The peak responsive wavelength of the tube is 0.83 μ. The tube will convert the radiation to green light at peak wavelength of 0.55 μ. Finally, the eyepiece L_5 will image the target on user's eye. The LIR reflected by BS_1 and mirror MR_1 will be imaged on the uncooled focal plane array Microbolometer (MBT) by the same front lens L_1 and different relay lens L_2 made by IR glasses. The tiny active matrix LCD immediately behind the MBT will convert the electronic LIR image to a visible image. The electronic board is in the battery pack. The lens L_3 will image the LCD on user's eye through mirror MR_2 and beam combiner BS_2 which will pass 100 % green light at 0.55 μ with a bandwidth of ± 0.01 μ from the tube (see Fig. 8) and reflect all other visible lights from the LCD. Therefore, it can get high intensities for both channels.

The user can either see the NIR image or the LIR image by simply touching a switch. By carefully design the lenses L_2 and L_3 or lenses L_4 and L_5 we are able to scale the LIR image or NIR image from the same target and let them overlap together correctly because the common optical aperture does not cause parallax. We also can put the IR digital video output into a buffer and scale the format and insert the data between pixels, thus we can get same format and resolution on the LCD as the I^2. By this way, two images can be fused together on user's eye clearly.

This kind common objective lens design is really an innovative and unique design because except the common front lens L_1, it uses different materials to make the relay lenses L_2 and L_4, thus we don't need to use same materials (only a few LIR materials available) to correct aberrations in the whole waveband from 0.6 to 12 μ. We only need to correct aberrations in the waveband from 0.6 to 0.9 μ for I^2, and from 8 to 12 for IR. Thus we are able to design a high resolution objective lens for I^2 (to design a low resolution objective lens for IR is relatively easy). The good design result are shown in Figures 9 and 10.

In the second approach, we will use a common beam splitter. As shown in Fig. 11, from the target radiation, the beam splitter BS_1 will pass 100% VIS and NIR from 0.6 μ to 0.9 μ and reflect 100% LIR from 8 μ to12 μ. The VIS and NIR will be imaged on the I^2 tube by objective lens L_3 made by common glasses and the LIR will be imaged on the MBT by objective lens L_2 made by LIR materials. The rest working and optical mixing principles will be as same as the first approach. Although the volume of this approach is bigger than the first one, we can directly use the LIR camera and I^2 goggle with much less modification than the first one and the image qualities of both sensors are much better.

In the third approach, we can either use common beam splitter or common objective lens, but the image mixing will be electronic. As shown in Fig. 12, in order to let the user have high resolution I^2 image directly viewed by his eye, the beam splitter BS_2 will split the I^2 output into two channels. 80% light will be imaged on user's eye by lens L_3, and 20% light will be imaged on CCD by lens L_4. The CCD output will be fused to the data fusion electronic board with the output from the MBT of the LIR channel. Since the I^2 image and LIR image can be digitized and stored into memories, we can insert the data and scale the images to let two images have same size and resolution, thus we can do image addition, subtraction and convolution, etc.

Because we will use common objective lens, 320x240/25μ microbolometer or Si-bolimeter without TE cooler and 16-mm Gen-IV tube, the size, weight and power of the FGS will be much less than the required limitations thus we are able to put 2 "AA" size rechargeable Lithium batteries on the FGS to let it become a stand along unit and it can operate for 4 hours. We also will put 4 "A" size Lithium batteries in a battery pack and hook it on the rear of the helmet as weight balance to let the gravity center on the center of the helmet. This battery pack can operate the FGS for 12 hours.

2. Function

In our design, both I^2 and IR cameras will use light-weight and high-strength plastic or space shuttle material to make the case and enclosure for camera lens, camera body, and display. Between the envelope and case, we will insert quarter-inch foam cut to further protect the FGS. On the inner surface of the envelope, a thin layer of metal net will be moulded to shield the magnetic electrical radiation. If we use manual Iris and Focus adjustment knobs, we will make a long lens cap with thin hot pressed ZnS window (it has high transmittance from 0.6 to 12 μ) to cover not only the lens but also the Iris and Focus knobs. We also will make a cap for the interpupillary distance adjustment knob. After adjusting the Iris and focus, and the interpupillary distance, the caps with attached rubber bands can be turned and tightened to the envelope thus waterproof is achieved. Similarly, we also will use waterproof membrane buttons for the brightness, contrast, polarity, calibration, image mixing, and focus controls, and the power on/off switch. If we use motorized Iris and Focus adjustments and motorized interpupillary distance adjustment, we also will use waterproof membrane buttons molded to the envelope. Thus the FGS will be a ruggedized system that allows the soldier to operate in battlefield environments even drop down the FGS on the ground it will not be damaged.

In order to use the FGS under adverse weather conditions (light rain, light snow, in darkness, and in daylight) to maneuver and identify targets, we will use a single bladed windshield wiper with a 1.41 ounce (40g) per inch load to circulate the slurry. The hot pressed ZnS window has very good mechanical performance (high hardness and melting point) and very good chemical stability (zero water solubility). Therefore, it can bear the wiper on the surface for long time without showing evidence of delamination, cracking, pitting, scratching and staining.

Yan: please don't disclose to anybody! Evan 1/15/2000

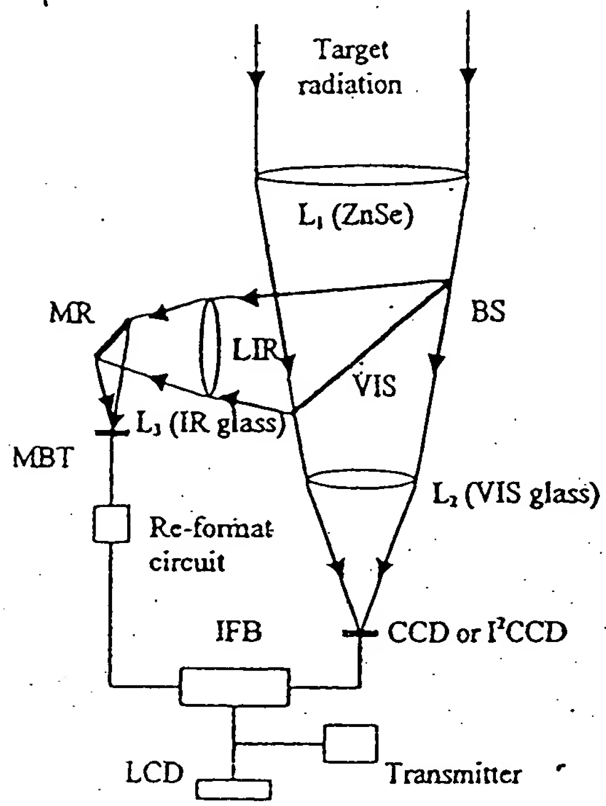

Fig. 1, Common refractive objective lens for sensor fusion

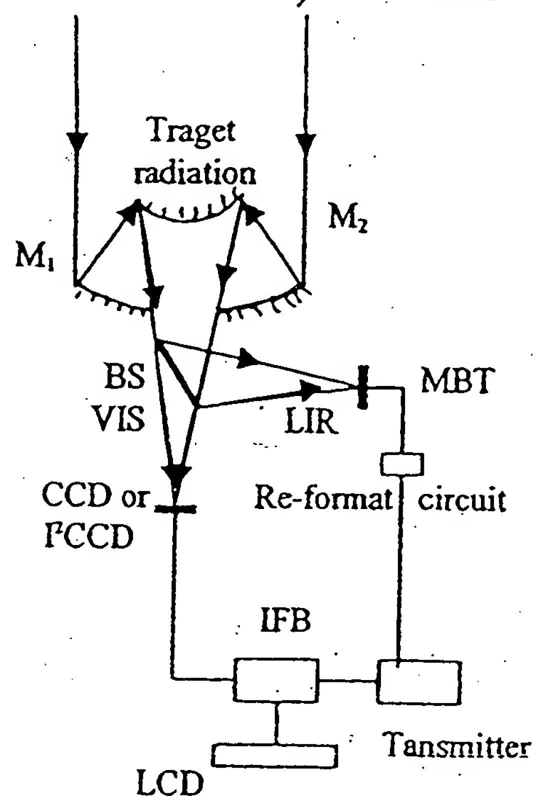

Fig. 2, Common reflective objective lens

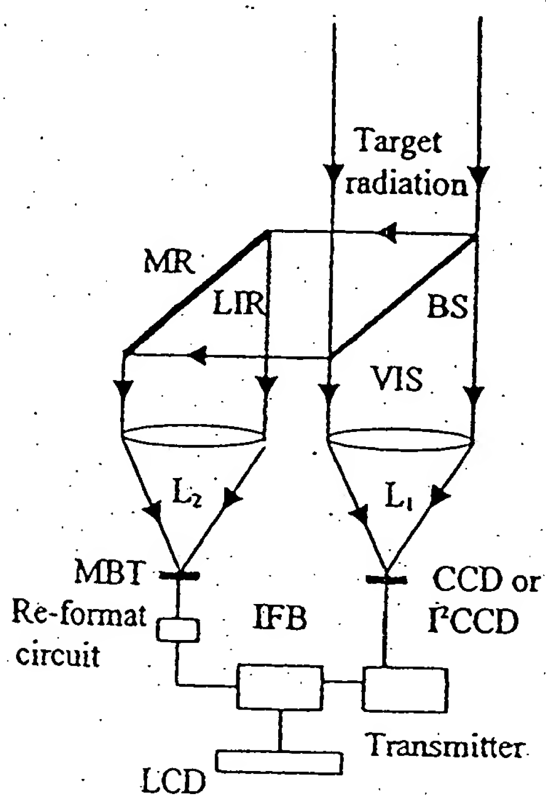

Fig. 3a, Common beam splitter

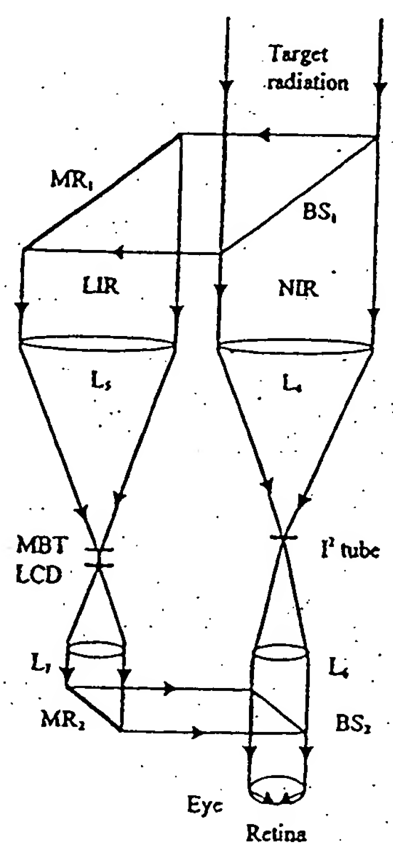

Fig. 3b, The optical fusion configuration of I^2 and LIR sensors

Fact 3 **EXHIBIT B**

00-CG1

Low Cost Night Vision System for High Speed Vessel Operations

Principal Investigator: Evan Zhang, Ph. D, Zybron, Inc.
Consultant: Gary Palmer, Ph. D, ITT Industries, Inc.

C. IDENTIFICATION AND SIGNIFICANCE OF THE PROBLEM OR OPPORTUNITY

The availability of the 13-meter class deployable pursuit boat with its exceptional maneuver and high-speed capability has provided increased surveillance, pursuit, interdiction and search and rescue capabilities to the Coast Guard. The expanded mission roles, particularly for night covert and non-covert operations that these boats can support, put increasing demands on the operators to assure safe and effective operations. Current night vision technology assets available to the Coast Guard's support of night operations also have substantial liabilities and limitations, particularly for the highly dynamic environment in radical maneuvers. When the boat travels at speeds of 50+ miles per hour in harsh environments i.e. seawater and vibration including large and continuous attitude changes that will cause rapid and large head movement. The gravity center of the current goggle is far away from the head center thus head and neck injuries often occur because large stress and torque will be put on the head and neck. The current head-mounted AN/PVS-7C goggle at a minimum produces extensive neck fatigue in even comparatively benign environments for longer missions.

At best successful and safe night operations pose special challenges. These are exacerbated by the high-speed operations and maneuvers, often-poor atmospheric transmission and high sea states. Night vision operations often required near and distant targets locations, identification and tracking, augmentation of conventional navigation techniques, timely location of debris in the boat's path, finding people in search and rescue operations, etc. All these require long detection distance and large field of view, but the detection distance of the current goggle is too short (a few hundred feet) and the field of view is too narrow (40 degrees, that is much narrower than eye). In addition, the price of the current night vision goggle is too high (over $12 k), not every crew member can use.

In order to let the DPB crew effectively and safely accomplish night high-speed pursuits and interceptions, covert and non-covert operations, and other missions in harsh ocean environment, in the Phase-I study, we must understand and quantify to the extent practical what are the proper night vision requirements that must be met by the night vision equipment and the key personnel, particularly the coxswain and the navigator as indicated Coast Guard priorities, and how can we satisfy these requirements. In order to do so, following problems must be first considered:

a. Environmental limits

Since the DPB is on the rough ocean, the most important issue is to understand the environmental limits that are quite different from ground operations. Following factors will seriously affect the normal performance of the night vision goggle/imager and also the night

vision operation: rough sea state, high-g, torque, salt water immersion, vibration, shock, temperature impact, and electromagnetic field interference. During the phase-I study we must create innovative night vision goggle/imager design to quantitatively determine what kind conditions/requirements are acceptable: At what kind sea state (1 - 5) the operation will be functional? At what kind speed and g the operation will be safe? What is the maximum torque permitted that will not hurt the neck and head? How long and how deep are the permitted salt-water immersions? What are the acceptable frequency ranges and applying forces for the vibration? What is the height of dropping down the goggle/imager without damage? What is the highest and lowest temperature impact allowed? How large is the tolerance of the electromagnetic field interference? And so on.

b. Detection range

The current night vision goggle typically uses a 25-mm objective lens with an F number of 1.3. Therefore, the range of detecting a human on the ocean at the full moon condition will be only a few hundred feet. High sea state and fog will further reduce the detection distance. It is obviously too short. This is a major problem to be overcome for the night vision goggle. Although we can design a bigger objective lens with longer focal length, it will increase the weight, further move the gravity center away from the head center and create larger torque and stress to the head and neck. We must create innovative design to increase the detection distance but not increase the weight and torque.

c. Field of view

The Field Of View (FOV) of current goggle is 40° (further increasing FOV will reduce the image quality). It is much narrower than the human eye. It is possible to increase the FOV to 80° similar to the pilot goggle with double binoculars, but the cost will be much higher and it will add extra weight on user's head and neck. How can we increase the FOV without increasing the weight and cost is an important problem to be solved.

d. **Acuity**

Following table shows the on-axis goggle resolution required by Army and SOF:

Light Level (Lux)	Threshold Resolution (cy/mr)	Objective Resolution (cy/mr)
1.0 x 10^2 to 10^2 (Dark to Bright Day)	.18	0.76
1.0 x 10^{-1} (Full Moon)	.76	1.45
1.0 x 10^{-2} (Quarter Moon)	.76	1.4
1.0 x 10^{-3} (Moonless, Clear)	.68	1.2
1.0 x 10^{-4} (Moonless, Overcast)	.55	1.0

Since the environment condition is quite different, we must give an answer if we should keep the same Acuity requirement. In addition to the Acuity, we also should give the requirements of output brightness, objective focus continuity, bright flash light protection, and so on, to the goggle. If the night vision equipment is a thermal imager, the requirements will be completely different.

e. Situation awareness and depth perception

Quantification of performance requirements in areas such as "situational awareness" and "depth perception" are expected to particularly challenging. Initially the input is expected to be based on what the operator believes he needs to be able to do contrasted with what he does in daytime or bright clear moon nights with no night vision assistance. Now he must optimally use the goggle to deal with the situations of different sea sates, different ambient light conditions, pursuit and intercept with different speeds, covert and non-covert operations that will affect the depth perception, to better identify targets. Developing a quantified description of what an operator requires regarding ease of use, visual cues, local and off-board, horizon orientation, resolution detail from distant identifiable markers, features or objects, etc. may bear on a meaningful requirement definition for situational awareness and depth perception. In order to get better result, we must consider the goggle design instrumentally and psychologically, i. e., it involves human factor considerations.

f. Weight and center of gravity for head-mounted display

Since the operator with head-mounted night vision goggle is on a high-speed pursuit boat, the high g impact to his head and neck is critical. Therefore, to reduce the goggle weight as much as possible and move the center of gravity as close as possible to the head center are very necessary. The current goggles having long optics are basically designed for low speed ground soldiers not for high speed boat crews, thus a new goggle design must be created.

g. Weight balance, torque and goggle location

On a high-speed pursuit boat, weight balance for the helmet mounted goggle is important. Current goggle has straight forward long objective lens in the front of the goggle, it not only will cause goggle slip from helmet, but also will create large stress and torque during the nighttime pursuit and intercept when the boat travels at speeds of 50+ miles per hour in harsh environments i.e. seawater and vibration including large and continuous attitude changes. It will injure the head and neck of the user. Therefore, how can we create a new design to balance the weight, reduce the torque, and properly locate the goggle on the helmet and let the gravity center close to the head cenetr that is a important problem to be solved.

h. Infrared illuminator

During the darken night, to use an infrared illuminator will be helpful to increase the detection distance and identify the target. SOF uses a dual field-of-view infrared illuminator that operates at 850 nanometer which matches the peak spectral response of the Image Intensifier (I^2) tube of the goggle. The narrow field-of-view shall illuminate approximately 18 inches in diameter at a distance of 25 feet. The wide field-of-view shall illuminate the full 40 degrees of the field-of-view with shorter distance. Obviously, this kind illuminating distance is too short for the DPB. Although we can increase the laser output power, it will create the eye unsafe problem. How can we design a powerful but eye-safe illuminator is a difficult task.

i. Helmet mount interfaces

Presently Coast Guard is using AN/PVS 7C night vision goggles, thus the helmet must provide two different interfaces, one spring-loaded mount and one dovetail mount. The force of breakaway from the helmet mount during operations on high-speed boat and in rough sea environments should be quantitatively determined.

j. **Electronic image**

Because of the budget limitation, currently only the coxswain has the goggle. To let the navigator and other crewmembers see the I^2 image viewing by the coxswain will be very helpful. One solution is to convert the optical I^2 image to electronic image and wireless send it to other crew members. This kind design should be created. Since the resolution of the electronic image is much lower than the optical image, how can we let the coxswain still keep the high resolution image is a problem to be solved.

k. Head worn/Helmet mounted display

Usually, night vision goggle is head worn or helmet mounted and uses Liquid Crystal Display (LCD). The weight, gravity center, torque, and goggle location should be specified and carefully considered, because it relates with the possible head and neck injuries. For the LCD, there are many factors should be quantitatively determined such as Exit Pupil Diameter, Eye Relief, Brightness, Shades of grey, Display Focus Continuity, Contrast, Image uniformity, Light Security, Display defects, Display adjustments, Frame rate, Battery location and low-battery indicator, and so on.

l. **Head-up display**

In addition to the electronic I^2 image and the head worn display, in order to see a distant target, low light level camera, image intensification, and infrared imager should be adopted to help the night vision. Therefore, a head up display mounted beside the eye or mounted on the windshield displaying these images will be helpful. Some important data such as speed, direction, GPS also can be displayed on the head up screen. We need to put the specifications to the head-up display and carefully design the display.

m. Optional devices considerations

In order to enhance the performance, we also can add optional devices to the goggle and its related sensors, for example, Zybron had developed following devices: wireless video & audio communication unit between crew members and commanders, hands-free voice activated switch, automatic target recognition hardware and software, and pseudo-colour representation for the B&W I^2 and IR images. They should be adopted to the night vision.

From the above understanding we can see that many requirements are not easy to be quantitatively set up and will involve risk. Our objective is to produce a quantified or at least semi-quantified description of performance parameters which are ranked according to their value in enabling the operator perform his mission functions effectively. For the highest importance ranked parameters, the effort will be made to fully quantify the performance.

During the phase-I study, in addition to our interviews with Coast Guard operators regarding requirements and operations, and with the SBU and possibly with the Seal DEV Group, we may solicit the Naval Surface Warfare Center, Crane Division, for requirement data which they may have acquired as part of their support role for development of night vision equipment for special and regular naval force units. Based on the proper requirements set up, we will design our innovative goggle/imager to satisfy the requirements and most effectively help the night vision operation on the high speed boat and rough ocean.

D. PHASE-I OBJECIVES

High-speed, night intercepts have created a need for Coast Guard boat crews, especially the coxswains, to have high quality night vision. A new low cost night vision device should be developed that is capable of providing the necessary acuity, depth perception, and situational awareness needed during high-speed maneuvers and intercepts. This system would allow the operator to see the sea state to maneuver safely, and allow for covert operation for high speed intercepts. Non-covert modes of operation may be used for transiting, and search and rescue, and other missions. The visual information provided by the system should not detract from mission performance.

The new system design should prevent of head and neck injuries because the boat can travel at speeds of 50+ miles per hour in harsh environments i.e. seawater and vibration including large and continuous attitude changes that will cause rapid and large head movement. If the gravity center of the goggle is not close to the head center, large stress and torque will be put on the head and neck. In addition, the detection distance of the current goggle is too short and the field of view is too narrow, the new system design should also overcome these important problems. Besides, currently only the coxswain has the goggle, to let every crew member see the night vision image will be our objective.

In order to let CG have a practical experience for our new design and make a right decision for Phase-II, during the Phase-I research, we will not only do the feasibility study and the investigation of possible techniques for the development of a night vision system, but also will deliver a prototype to CG for field testing. It means that we will not only finish the Phase-I task but also a part of Phase-II task.

E. PHASE-I WORK PLAN

In order to overcome the problems mentioned in Paragraph C and realise the objectives stated in paragraph D, suitable requirement parameters for the night vision equipment on the high speed boat will be given and very innovative night vision goggle, uncooled thermal imager, LLL CCD, and their fusion systems will be designed to satisfy the requirements. Following is our solid work plan.

1. Innovative Image Intensifier Goggle Design

The I^2 has low power consumption, high resolution and can clearly identify the target under the ambient light, but the distance of detecting a human is only a few hundred feet, and it is even shorter for a fast boat on the rough ocean. We must overcome this key problem. Our goal is to design a new goggle that can increase the detection distance to at least 1,000 feet.

Because the sensitivity of the I^2 can not be largely increased at the current time, there are only two ways to increase the detection distance: enlarge the objective lens or use more powerful illuminator. However, as mentioned in paragraph C, the larger and longer optical lens not only will increase the weight of the goggle but also the torque. Larger torque is more dangerous than weight for the user on a high speed pursuit boat. It will seriously cause head and neck injuries. Therefore, we must reduce the torque to let the gravity center of the goggle

as close as possible to the center of the head. It is also mentioned in the paragraph C that to increase the laser illuminator power will increase the risk of eye injury, we must design a new illuminator that is eye safe.

a. Folded optical path design

As shown in Fig. 1, most of goggle designs have straight forward long objective lenses in the front of the goggle, thus the gravity center of the goggle is far away from the head, it not only will cause the goggle slip, but also will create a large stress and torque on the head and neck for a user on the high speed boat. Therefore, we can not simply enlarge the optics to increase the detection distance; we must have an innovative design that can enlarge the optics but reduce the torque. This solution is to use a folded optical path. As shown in Fig. 2, the new design folds the optical path by two prisms and two mirrors, thus the total length of the optics will be only 1/3 of the straight one. If we use 50-mm focal length with same F number of 1.3 to replace the current 25-mm lens, the length of the optics will be still half of the 25-mm lens. Therefore, the torque of the larger lens is even smaller than the smaller lens because its gravity center is closer to the head center.

b. See-through eyepiece design

Normal eyepiece of goggle has no ability to see outside directly by eye. In the harsh ocean environment (such as high sea state, moonless, and fog), user's eye probably has better detection distance and larger field of view than goggle, therefore, as shown in Fig. 2, we use a beam splitter not a mirror before the eye, it will reflect 100% of the green light at 0.55 μ with bandwidth of ± 0.01 μ created by the phosphor of the Image Intensifier (I^2) tube and pass 100% visible light at other wavelengths, thus the user not only can see the I^2 image but also the outside targets clearly. This new design not only will increase the safety for the user because the goggle will not block his normal vision, but also will gain the situation awareness.

c. Aspherical objective lens design

In order to reduce the weight and increase the field of view of the objective lens, an aspherical objective lens will be designed. Because less optical elements are used, the weight can be reduced to ¾ of the spherical lens. Since the aspherical lens can correct the aberrations much better than the spherical lens especially at the large FOV, according to our preliminary design, keeping the same image quality the FOV can be increased to 50 degrees. In the past, not only to design an aspherical lens was difficult, to make the lens was more difficult and more time consuming. By using the automatic lens design software developed by the principal investigator and the diamond turning machine, the aspherical lens design and fabrication become easy.

d. Weight balance consideration

In order to prevent the goggle slip, an extra power supply pack with electronic baords is put on the back of the helmet and very close to the head, it not only will solve the weight balance problem, but also will move the goggle gravity center to the center of the head.

2. Eye safe infrared illuminator design

Current I^2 uses IR laser illuminator, for eye safe operation, the illumination distance is short. Further increasing the laser power will cause eye injury. However, the I^2 needs much longer illuminating distance, this is a difficult problem to be solved.

As shown in Fig. 3, by using our patented parabolic LED (in contrast with common LED, the parabolic LED can collect 100% light and project it to a long distance), a search-light type IR illuminator is designed. The LED light is 100% eye safe. It will use the power supply mounted on the back of the helmet mentioned above, and will illuminate at least 1,000 feet. Actually, we had built a parabolic LED search light for Navy to conduct ships to the harbour 10-km away. The LED lamp can be either visible or invisible.

3. See-through fog filter design

It is well known that, except Radar (but the resolution is too low and the volume is too big), Visible, NIR, and MIR imagers cannot see through fog and LIR imager can only see through light fog. However, our recent research had discovered that the circularly polarized light would reverse the direction in which it rotates when singly scattered from most hard surfaces, fogs and aerosols. However, for most "real-life" surfaces, i.e., any surface that is slightly diffuse, a surprisingly large amount of the reflected light retain their original circular state. This should allow the effective light discrimination (and subsequent removal) of turbid medium scattered noise light that typically negates the benefit of active illumination. For example, let's assume right-handed circularly polarized NIR light is used to illuminate a fog cloud that obscures a target of interest. Normally much of this light is scattered back into the imager causing a "white-out" condition and rendering the illuminating light useless.

By using the polarized nature of the light, we can discriminate and remove the unwanted backscattered light and allow only the "image-forming" light reflected from the target to reach the camera. With an additional right-handed circular polarized filter in front of the camera, all backscattered light from the turbid medium is removed since upon reflection it becomes reversed, i.e., left-handed.

By using eye-safe LED or laser diode at peak wavelength of 0.85 μ and right handed polarizer/filter to the LLL CCD camera or Image Intensifier, our experiment had sown that the fog was largely removed and the person could be clearly seen on the screen (see Fig. 5).

4. Innovative I^2 and IR sensor fusion system design

Although the I^2 can clearly see a person's eyelash, it still has fundamental limitations: it has short detecting distance, can not be used during the day time and under strong light, and can not see through smoke, fog, disguise and darkness (in combat situation the illuminator is not suitable to use). In order to overcome these shortcomings, we will fuse the IR image to the I^2 image because the IR imager does not have these problems. However, the IR resolution is too low for target identification. So we still need I^2. If we have the sensor fusion system, under the normal star, moon, and ambient lights, the I^2 goggle will clearly identify the target; under the harsh environment, the IR imager will reveal the distant target. Therefore, the I^2/IR

sensor fusion system is the ideal system for CG. It can take the advantages of both sensors and overcome the shortcomings of both sensors. Now let us design this sensor fusion system.

a. Common objective lens design

To design the sensor fusion system is very difficult. If independent objective lenses are used for both sensors, it will create parallax, thus it is almost impossible to overlap two images together correctly. Therefore, we will design a single objective lens for both sensors. Before the lens design, we must find suitable optical materials for both NIR to LIR first.

After deep investigation we found that crystal or polycrystal ZnSe and infrared glass $Ge_{33}As_{12}Se_{55}$ have high transmittances from 0.6 μ to 12 μ, therefore, they are suitable for common objective lens design. However, it is impossible to correct the aberrations for a very broad waveband from 0.6 to 12 μ. We must create very innovative idea. As shown in Fig. 4, a common front lens L_1 made by 2 pieces of ZnSe will be first designed for both I^2 and IR channels. After L_1, a beam splitter BS_1 will be inserted to pass Near Infrared Radiation (NIR) from 0.6 μ to 0.9 μ and reflect Long Infrared Radiation (LIR) from 8 μ to12 μ. For simplicity, on the diagram we only show an infinite target on the optical axis (actually the objective lens has 50° field of view) and only show the NIR channel. The NIR will be imaged by L_1 and its relay lens L_4 made by normal glasses that can further correct the aberrations in the 0.6 to 0.9 μ waveband and get high resolution image on the I^2 tube. The peak responsive wavelength of the tube is 0.85 μ. The tube will convert the radiation to green light at peak wavelength of 0.55 μ. Finally, the eyepiece L_5 will image the target on user's eye. The LIR reflected by BS_1 and mirror MR_1 will be imaged on the uncooled focal plane array VOx Microbolometer (MBT) or Silicon Microbolometer by the same front lens L_1 and different relay lens L_2 made by IR glasses to further correct the aberrations in the 8 to12 μ waveband. A tiny active matrix LCD immediately behind the MBT will convert the electronic LIR image to a visible image. The electronic board is in the battery pack at the rear of the helmet. The lens L_3 will image the LCD on user's eye through mirror MR_2 and beam combiner BS_2 which will pass 100 % green light at 0.55 μ with a bandwidth of ± 0.01 μ from the tube and reflect all other visible lights from the LCD of LIR channel. Therefore, it can get high intensities for both channels. The user can see the NIR image, or the LIR image, or the NIR/LIR overlapping image by simply touching a switch. By carefully design the lenses L_2 and L_3 or lenses L_4 and L_5 we are able to scale the LIR image or NIR image from the same target and let them overlap together correctly because the common optical aperture does not create parallax. Fig. 6 shows the NIR/LIR optical sensor fusion system, in which the LIR camera is put on the top of the military helmet mount and the I^2 is put below.

In addition to the above optically fused image, we also can electronically fuse two images. As shown in Fig. 7, we will put a CCD camera behind the I^2 tube to convert the optical image to an electronic image. After A/D converter, we will feed this digital electronic image with the digital electronic image from the MBT into a buffer for image processing. Since the resolution and format of two images are different, we must insert pixels for the LIR image to let it have the same resolution and format of the I^2 image. After that, we are able to do image addition, subtraction, convolution, enhancement, colorization, etc. to get much better target identification.

In order to let the user keep high resolution I^2 image in the electronic sensor fusion, we can put a beam splitter behind the tube. 80% light will go to the eye for direct observation and 20% will go to the CCD. The CCD output will be electronically fused to the electronic image from the IR.

Since the electronic image is easy to be manipulated by computer, we can use two independent I^2 and IR cameras to fuse two images together. Although to exactly overlap two images is difficult because of the parallax, to put two images picture in picture or side by side is easy. If we hope to roughly overlap two images we can use a video switch chip to display the I^2 and IR images alternatively on the screen with acceptable speed, thus two images will not be blurred because actually they are not overlap together at the same time. We call this innovative sensor fusion method as time-share method.

b. Tiny LIR camera design

In order to reduce the weight and torque, it is important to design a very small and very light LIR camera. We will use recently developed Si-bolometer, it does not need TE cooler and only uses 2 "AA" batteries. The only problem is that the traditional electronic boards of the contemporary LIR cameras are too big and too heavy. In our innovative design, as shown in Fig. 8, we will use only one Altera chip to do all digital image processing such as non-uniformity, off set, dead pixel corrections. Therefore, a 2-ounce LIR camera can be built and mounted on the military helmet. This camera will be the smallest and lightest LIR camera in the world. Both I^2 and LIR cameras will be put in the front of the helmet and the sensor fusion electronics will be put into the battery pack at the rear of the helmet. Good weight balance can be realised.

5. Head-worn display and head-up display designs

The electronic images will have a head-worn display. The selection of optimum display depends upon many aspects such as electronic interface, weight, and cost. Some of other factors such as color or monochrome, resolution, video format, refresh rate, package size, interconnection, drive circuitry, power supply voltage, mass, center of gravity, environmental specifications, operating/storage temperature, vibration, impact, etc., are also important. We have tentatively selected the Liquid Crystal Display (LCD) as our display, because the LCD has many advantages over other displays, such as very low power, low driving voltage, paper-thin thickness, readable in bright environment, and materials available from many manufacturers.

There are three types of off-axial LCD optical systems: hologram, mirror and prism. We will design the prism as our LCD optical system, because it is the best one. As shown in Figure 9, the closed prism system consists of two devices: the LCD unit and the prism. The prism has two off-axial reflective surfaces. The rays from the LCD are reflected between these surfaces and the eye. A paper-thin (15 mm) system with 48° Field Of View can be realised.

To correct the off-axial aberrations, the aspherical surfaces without rotational symmetry are used in this prism. The optical loss in this optical system without any half mirrors is almost zero.

For the transparent (see-through) system, as shown in Figure 10, the optical system consists of a half mirror, two prisms and a LCD unit. If the curved outside surface of the Prism 1 is the half mirror, the transparent capability is given by the refraction and the power of the Prism 1. Attaching the compensation prism to the outside of the prism, transparent viewing is achieved. Two aspherical surfaces without rotational symmetry can be fitted and joined accurately.

In order to let the coxswain or navigator clearly see the I^2, IR, and their fused images on a larger screen with other data such as GPS, speed, direction, temperature, sea state, etc., a head-up display mounted on the windshield similar to the automobile Cadillac will be designed (although our head worn display also can accept these inputs). These images will be projected from the LCD or CRT to the windshield with a see-through beam-splitter screen. By heading up (or down) to the screen, the operator is able to see the images without blocking his vision to the outside world.

6. Weight and cost reduction considerations

In order to reduce the weight and cost, we will use uncooled 160x120/50 μ Si-bolometer, and monocular, 16-mm, filmless, and gated I^2 of Gen-IV to make the fusion system, thus the total weight of the sensor fusion system will be less than the binocular 18-mm I^2 of Gen-III, and the price will be similar to the current binocular I^2 goggle (about $12 k). Because of the integration of the LIR camera, the detection distance can be 5 times longer than the I^2 goggle, and the sensor fusion system is an all weather system with unbeatable performance mentioned before. Therefore, much better situation awareness and depth perception can be obtained. Fig. 6 shows one of our I^2 and IR sensor fusion system mounted on the military helmet.

Since the I^2 goggle occupies 3/4 of the total weight and 1/2 of the total price of the fusion system, we will consider replacing the I^2 goggle by Low Light Level (LLL) CCD camera. Although the resolution of the LLL CCD is only 1/2 of the I^2 goggle, the sensitivity of the LLL CCD is 0.00015 Lux, it is close to the sensitivity of 0.0001 Lux of the I^2, and the weight of the LLL CCD is only 1/3 and the price is only 1/30 of the goggle. Fig. 11 is our LLL CCD/LIR fusion system with separated heads. Two images are displayed picture in picture or side by side.

7. Wireless transceiver design

As mentioned in paragraph C, because of the budget limitation, currently only the coxswain has the goggle. In order to let every crewmember see the night vision images, as shown in Fig. 12, a gum-size wireless video and audio transmitter will be designed and put into the sensor fusion system. Every crewmember will have a wireless receiver and head-worn LCD to display the images from the sensor fusion system and listen the commands from the coxswain through the audio channel. Therefore, the total cost will be dramatically reduced.

Since our wireless transceiver can reach 1 mile through concrete wall and other obstacles, it is possible to let the commander on the commander boat or land head quarter to see the front images and talk with the crew members in real time. In addition, the whole night operation mission can be remotely taped for documentation and later analysis. Therefore, the wireless communication unit is very useful.

8. Harsh environment consideration

In order to let our I^2 goggle, IR camera, and their fusion system successfully used in the high-speed boat on the rough saltwater, we will design a good enclosure. The enclosure will be made by molded plastic with metal net and foam cut insert. By using robber band and o-ring nut, all lenses will be sealed with the enclosure. All buttons will use membrane buttons. Therefore, a low-cost, lightweight, solid, impact/vibration damped, waterproof, electrical magnetic field shielded, and high/low temperature resistant system can be realised. By using our special polarisation filter, the crewmembers are able to see through fog. This unique feature will be very helpful for CG.

9. Tasks and schedules

From the above designs we can see that we almost solved all problems mentioned in paragraph C. Following is a step-by-step approach to the effort that will give detailed tasks and schedules of the work plan.

Task 1 – New concept development (two months)

- Problem analysis and harsh environment consideration
- Current system advantages/limitations analysis
- Technical risk consideration
- New technology candidates analysis
- Requirements set up for night vision equipment and operation
- Requirements trade off
- New concept creation
- Overall system design
- High performance/low cost trade off

Task 2 – Innovative system design (three months)

- **New night vision goggle design**
  - Folded optical path design
  - Aspherical objective lens design
  - See-through eyepiece design
  - Weight balance consideration

- **Micro uncooled infrared imager design**
  - TE cooler elimination approach
  - Silicon bolometer adoption

- Aspherical non-germanium objective lens design
- Single Altera chip digital image processing circuit design

- **Innovative sensor fusion system design**
  - Parallax elimination approach
  - Three common optical aperture configurations
  - Sensor fusion algorithm
  - Optical image fusion and electronic image fusion
  - Weight and torque reduction consideration

- **Attachment design**
  - Eye safe IR illuminator design
  - See-through fog filter design
  - Wireless video & audio transceiver design
  - Helmet mounted display design
  - Head-up display design
  - Waterproof vibration resistant housing design

Task 3 – Utility assessment (two months)

- Theoretical evaluation of system advantages and shortcomings
- Experimental evaluation of system advantages and shortcomings
- Qualitative and quantitative analysis
- System improvement

Task 4 – Prototype fabrication and Demonstration (three months)

- New I^2 goggle prototype fabrication
- Micro uncooled IR imager fabrication
- I^2/IR sensor fusion prototype fabrication
- Waterproof case and other attachments fabrication
- Combination system and subsystems demonstrations
- Analysis and conclusion

Task 5 – Final report (one month)

- Detailed system and subsystem designs
- Detailed drawings and diagrams
- Parts and vendor lists
- Lab and field test results
- Quantitative data analysis
- System improvement suggestions

The above tasks and proposed schedules is shown in Table 1.

Table 1. Proposed schedule for the completion of the Phase-I tasks

Task	1	2	3	4	5	6
Task 1. New Concepts	←----	----→				
Task 2. System Design	←----	--------	----→			
Task 3. Utility Assessment			←----	----→		
Task 4. Prototype & Demonstration			←----	--------	----→	
Task 5 Final Report						←-----→

Month from contract starting

F. RELATED WORK

Zybron Optical Electronics, Inc., a minority firm with 8(a) status, had worked for DoD research for more than 12 years. Zybron had finished 5 phase-I and 4 phase-II contracts for the US Air Force and the US Special Operations Forces. These projects are directly or indirectly related with this phase-I effort.

1. 1988 - 1991, SBIR Phase-I and Phase-II from Rome Air Force Base.
   Contract # F30602-90-C-0028.
   Research area: "High Data Rate Holographic Optical Disk Head".
   Result: Completed the contract, delivered the prototype and got **Break Through** certificate from the Air Force (see Attachment 1).

2. 1990 - 1993, SBIR Phase-I and Phase-II from Eglin Air Force Base.
   Contract # F08630-91-C-0059.
   Research area: "High Speed High Density Video Data Memory".
   Result: Completed the contract, delivered the prototype and got **Break Through** certificate from the Air Force (see Attachment 2).

3. 1996 - 1999, SBIR Phase-I and Phase-II from Tyndall Air Force.
   Contract #: F08637-97-C-6014.
   Research area: "Hand-held and Helmet-mounted IR imagers Using Uncooled FPAs"
   Result: Completed the contract, delivered the prototype, had successful demonstrations in 7 cities and three countries, and the **Air Force had released Special News nation wide twice for Zybron's Invention** (see Attachment 3 & 4).

4. 1999 - 2000, SBIR Phase-I from the US Special Operations Forces.
   Contract # USZA22-00-P-0006.
   Research area: "Common Optical Aperture NIR and LIR Combination System".
   Result: Completed the contract, built up 3 working prototypes, negotiate phase-II contract.

5. 2000 - present, SBIR Phase-I from the US Special Operations Forces.
   Contract # USZA22-00-P-0029.
   Research area: "High Performance Assault Zone Marking System".
   Result: Completed the contract, built and delivered the working prototype, and had a successful field demonstration.

In 2000, by teaming up with JJMA, Inc., our team had won a 5-year contract from Coast Guard. In 2001, by teaming up with JJMA again, we have won another 5-year contract from Navy. Because of our outstanding achievements, Zybron was the only small business in Ohio received the SBIR Tibbetts award from the US government in 2000.

We believe the preceding examples had demonstrated that Zybron is well qualified to conduct the proposed effort.

G. RELATIONSHIP WITH FUTURE RESEARCH AND DEVELOPMENT

If the design of our system is acceptable to the CG, we will support the government field evaluation of our working prototype for 15 days at our own expense, and we will select the best system to be produced in Phase-II for massive production. The new night vision I^2, IR, and their sensor fusion system should satisfy all night vision equipment and operation requirements.

H. COMMERCIALIZATION STRATEGY

It is envisioned that this system could have wider application across CG boats and could eventually be marketed to recreational boaters for nighttime use, similar in concept to the night vision systems recently available in the automotive industry.

The technologies related to I^2, IR, sensor fusion, and their sub systems also will find large commercial applications such as fire fighting, law enforcement, security, etc.

I. KEY PERSONNEL

Zybron's key personnel include: Evan Y. W. Zhang, Ph. D., US citizen - Research Director, Senior System Scientist; James R. Atchison, MBA, US citizen - Program Manager, C. W. Yang, Ph. D., Permanent Resident pending – Senior Optical Engineer; and W. L. Song, Ph. D., Permanent Resident - Senior Electronic Engineer.

Principal investigator for this effort will be Dr. Evan Zhang. He got his BS in Solid State Physics and his first Ph. D in Infrared Technology in China. He got his second Ph. D in Electrical Engineering in USA. He specialises in the design and development of modern optical electronic systems that involve: night vision goggles, modern optical systems,

holography, LED traffic lights, uncoole IR imagers, missile tracking, neural net pattern recognition, analog and digital image processing, optical disk memory, and analog/digital circuit. He has published a 600 page technical book entitled *Infrared Optical Engineering* and more than 100 technical papers. He is recognised as a well-known expert in the areas of night vision and infrared technology.

He is a senior member of the Optical Society of America and a long-term reviewer of internationally recognised professional journal -- *Applied Optics*.

He got a National Outstanding Scientist title from the Chinese Prime Minister in 1986 before he came to USA, and he was nominated as an Outstanding Scientist of Great Dayton Area in 1992 by the Kettering Foundation. In 2000, he received the national Tibbetts Award from the US Government. Because of his outstanding achievement, he was invited as a special speaker in the Night Vision 99 conference held in London, England.

Mr. James R. Atchison, Executive Vice-President of Zybron will be the program manager for this effort. He specialises in financial, project planning and development engineering. He has experience in determining the technical, economic and commercialisation impacts of emerging technologies on special products. Mr. Atchison has developed long-term avionics development planning concepts for the United State Air Force because he was a former Air Force project manager. Mr. Atchison has published a book on the preparation of technical and cost proposals to various agencies of the United State Government entitled A Small Business Innovation Research (SBIR) Program Blueprint – 1997.

Dr. C. W. Yang is a Senior Optical Engineer of Zybron. He got his BS, MS, and Ph. D. in Applied Optics, and had published 2 books and 82 papers. He got three first place awards from Chinese Government before he came to USA. He had designed many modern optical systems. His solid theoretical background and excellent experimental skill will be very useful for this project.

Dr. W. L. Song is a Senior Electronic Engineer of Zybron. She got her BS in Applied Physics, and her MS and Ph. D. in Advanced Electronics. This spring, she also got her second MS in electrical engineering from Ohio State University. She had obtained two national awards from Chinese Government before he came to USA. She has extensive experience in the Analog; Digital and Integrated Circuits designs using Altera chip, and has rich knowledge in Digital Image Processing.

J. FACILITIES/EQUIPMENT

Over the past 12 years of operation Zybron has created the following laboratories within its 5,000 square feet facility in Dayton, Ohio to accomplish the Phase-I effort.

1. Optical Lab -- Optical table, uncooled infrared imagers, image intensifier night vision goggles, laser diodes with power supplies, LED manufacturing machines, laser/LED induced fluorescent materials, high speed LLL CCD cameras, interferometric devices,

holographic systems, rewritable optical disks, optical memories, fiber communication systems, optical-mechanical components and calibration equipment.

2. Electronic Lab – Digital signal processing hardware and software, A/D & D/A converters, spectral analyzer, signal generator, logical analyzer, imaging board, head tracking device, Altera chips with VHDL, satellite communication systems, and an array of electronic instruments.

3. Computer Lab – Many computers and LANs supported by advanced image processing, data analysis, and optical system design software.

4. Machine Shop -- Machines and tools for optical-mechanical works.

K. CONSULTANTS

We will invite Dr. Gary Palmer at ITT night vision lab as our consultant. He is very experienced in the night vision goggle design. We also will invite Dr. Dennis Brown at Ohio State University as our consultant. He is well known in the areas of Analog; Digital and Integrated Circuits designs using Altera chip.

L. PRIOR CURRENT OR PENDING SUPPORT OF SIMILAR PROPOSALS OR AWARDS: None

M. COST PROPOSAL: See Attachment C

N. REFERENCES

[1] Y. W. Zhang, **Infrared Optical Engineering**, Scientific Press, 1994.

[2] Evan Y. W. Zhang, "Active and Passive IR Imaging Systems", invited paper, **International Night Vision Conference**, London, England, 1999.

[3] Evan Y. W. Zhang, "I^2 and LIR sensor fusion system", **Phase-I final report to SOF**, Jan., 2001.

[4]Y. W. Zhang, et al, "Quantitative Measurements of Ambient Radiation, Emissivity, and True Temperature of A Greybody: Method And Experimental Results", **Applied Optics**, V. 25, p. 3683, 1988.

[5] Y. W. Zhang, et al, "Automatic Design of Optical Systems Using A Set of General Skew Ray Tracing Formulas", **Applied Optics**, V. 31, p.1547, 1992.

[6] Evan Y. W. Zhang, **Uncooled Infrared Imager For Fire Fighting Applications**, Phase-II Final Report to Tyndall AFB (AD report), Dec., 1999.

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[8] P. R. Norton, "Status of Infrared detectors", **SPIE**, V. 3379, p. 102, 1998.

[9] Y. W. Zhang, et al, "Equivalent blackbody radiation theory and its use in the radiation property measurement of a semi-transparent body", **Applied Optics**, V. 28, p. 482, 1989.

[10] Y. W. Zhang, et al, "Quantitative measurement of radiation properties for opaque and semi-transparent greybodies", **Infrared Physics**, V. 30, p. 149, 1990.

[11] John L. Jackson, et al, "Automatic Docking System Sensor Analysis & Mission Performance", **SPIE**, V. 3380, p. 327, 1998.

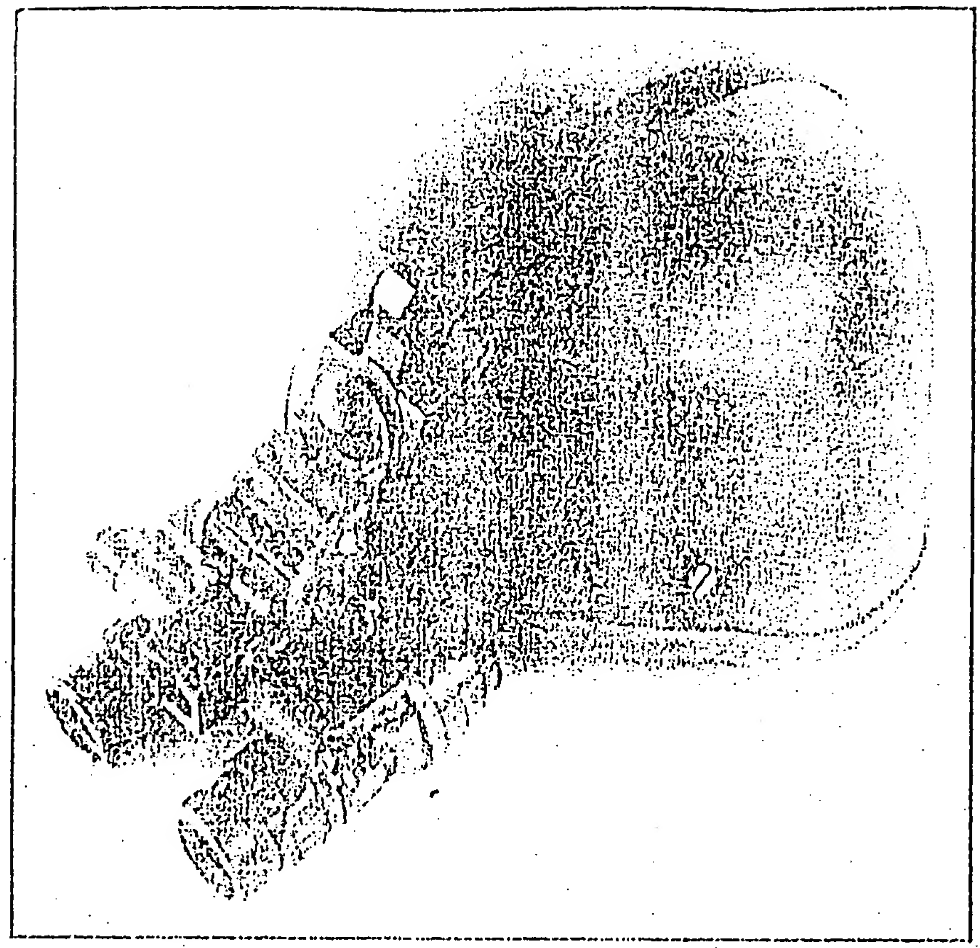


Fig. 1, Conventional objective for I^2

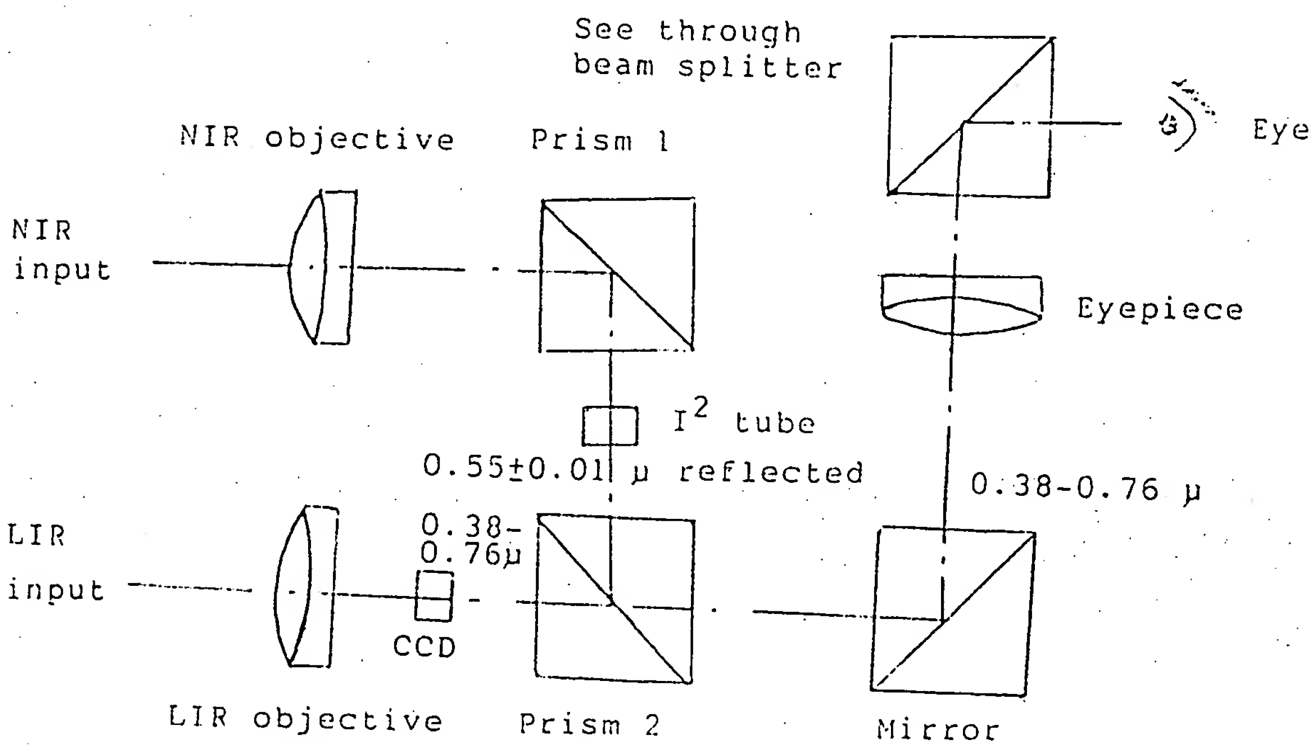


Fig. 2, Folded optical path for night vision goggle with optional LIR input for optical sensor fusion and see through display

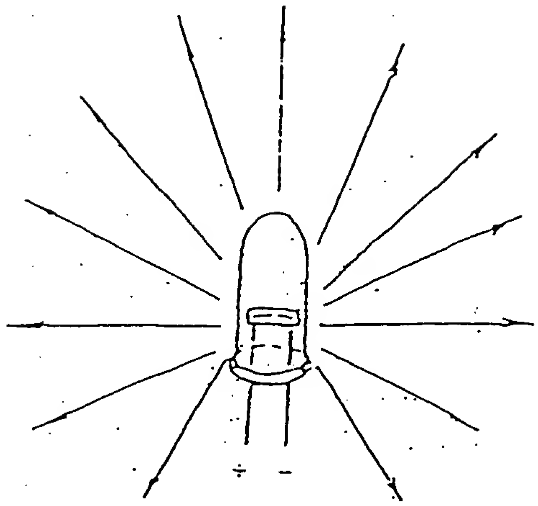


Fig. 3(a), Common LED

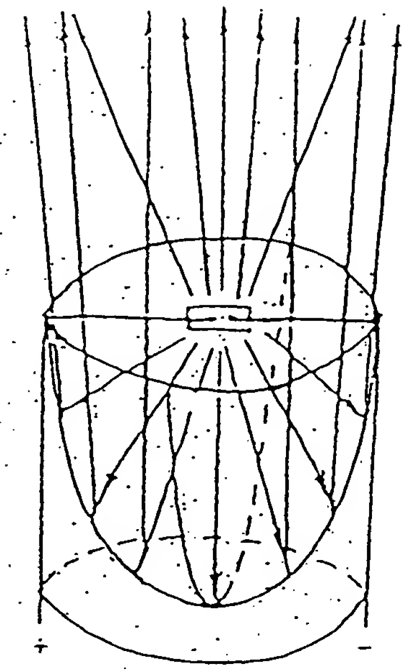
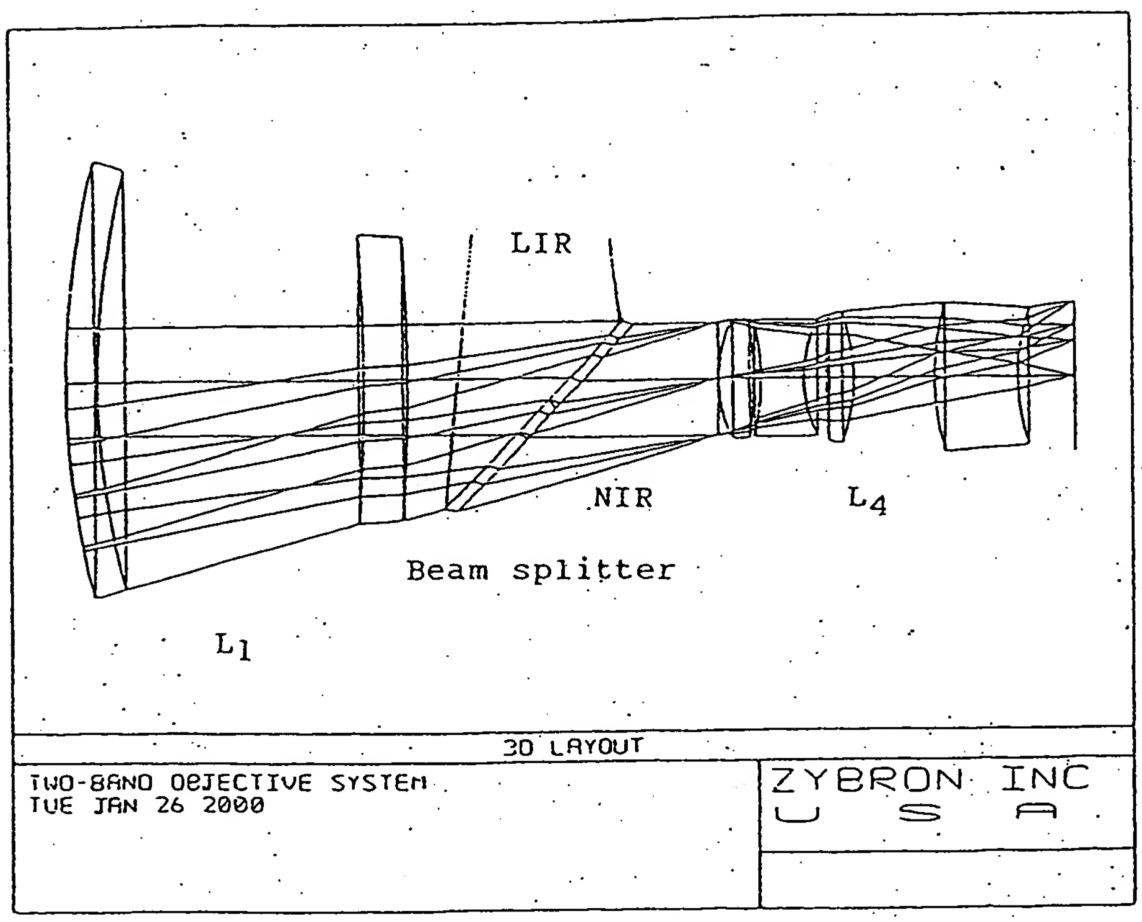


Fig. 3(b), Parabolic LED



Optical Layout of NIR Follow-up Lens

Fig. 4, Common Objective Lens

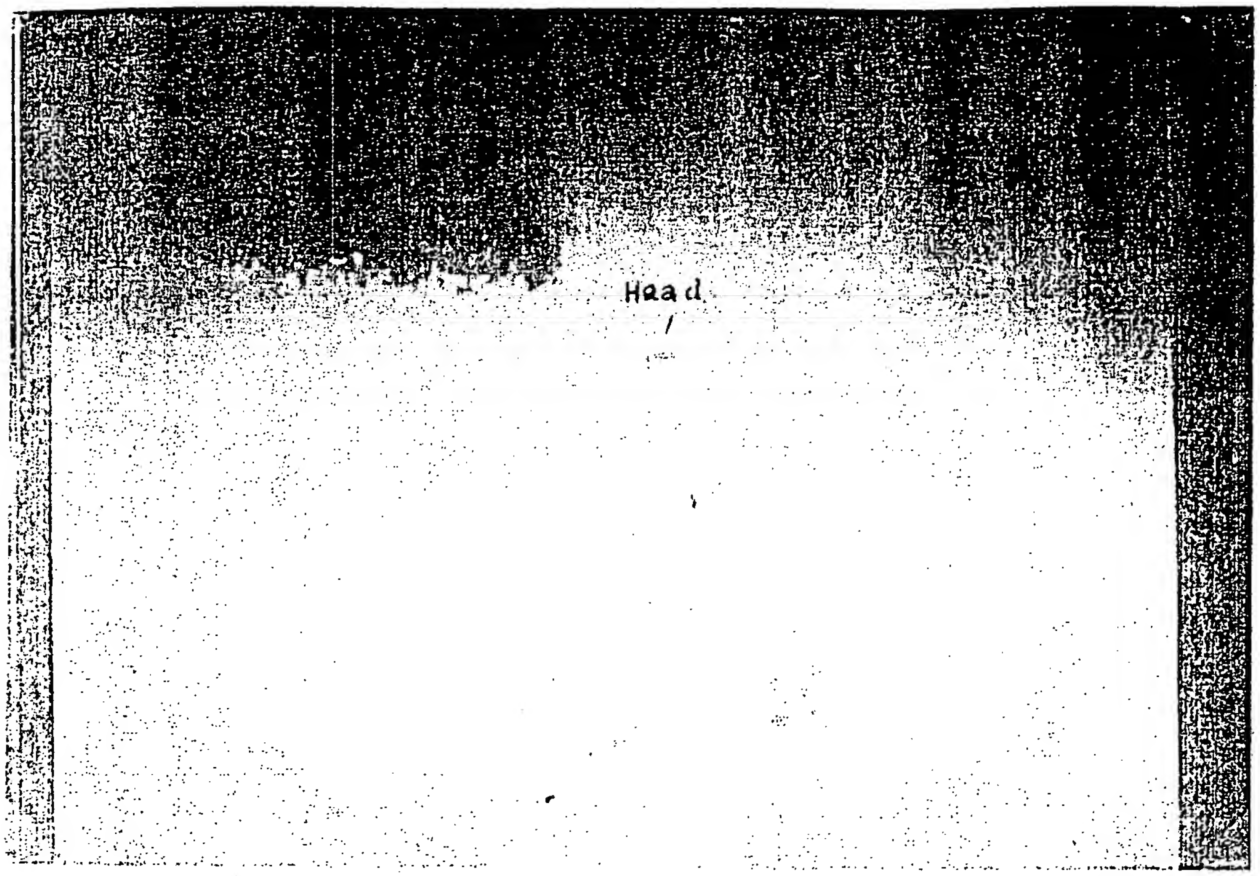


Fig.5a, A person in fog before applying polarization filter

Fig.5b, A person in fog after applying polarization filter

Fig. 6 , I^2 and IR optical fusion system; one image inside another image.

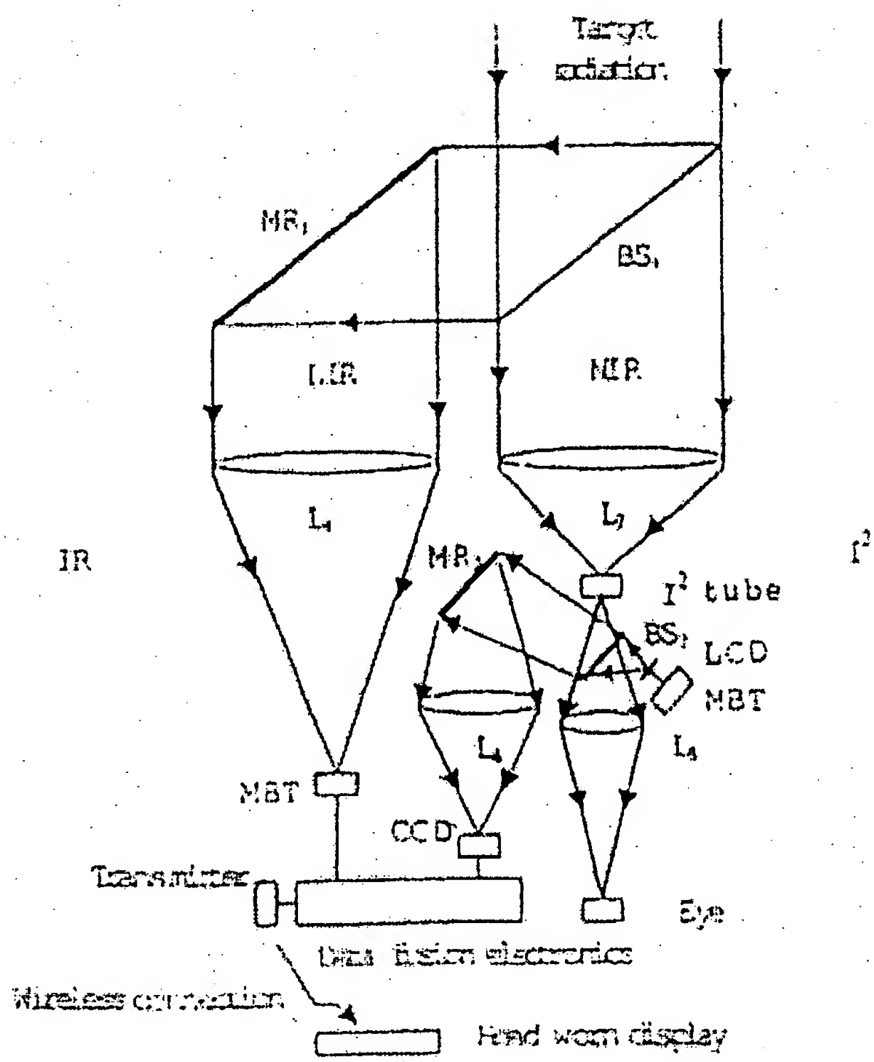


Fig. 7 .The common beam splitter approach for the I^2 and IR fusion system with optical image and electronic image

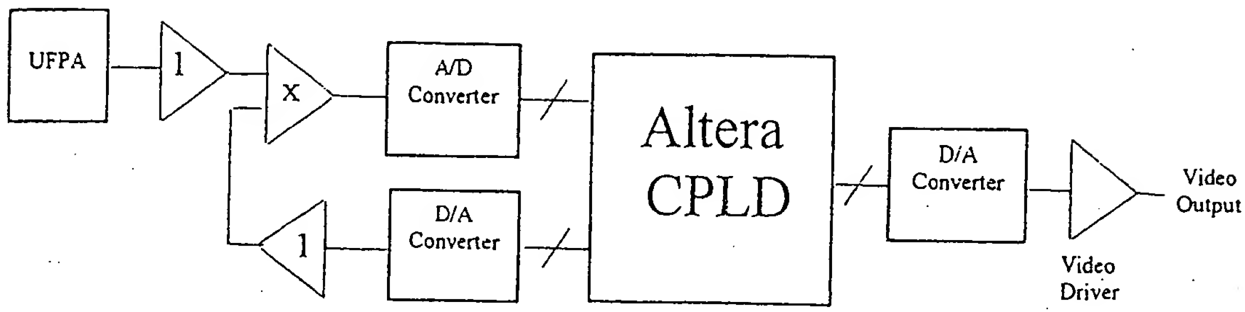


Fig. 8 (a), Zybron Electronics System For UFPA

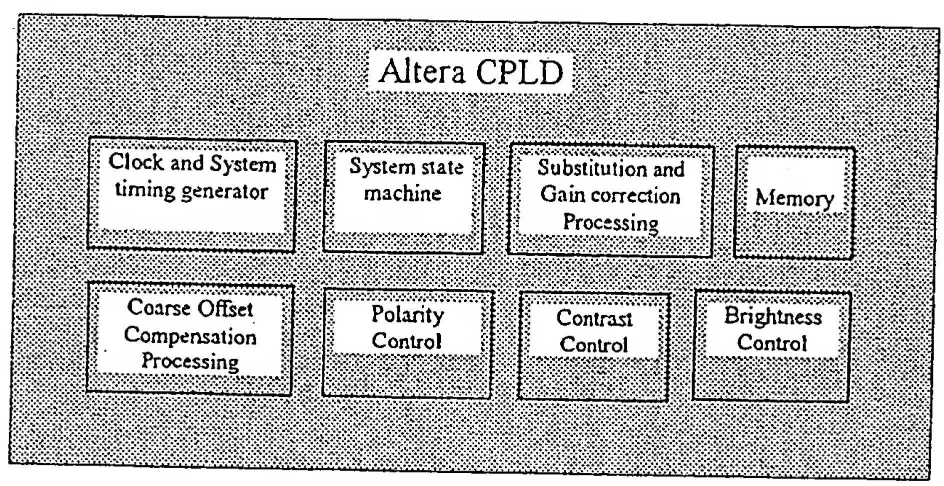


Fig. 8 (b), Digital Processing Functional Block Diagram for Altera CPLD

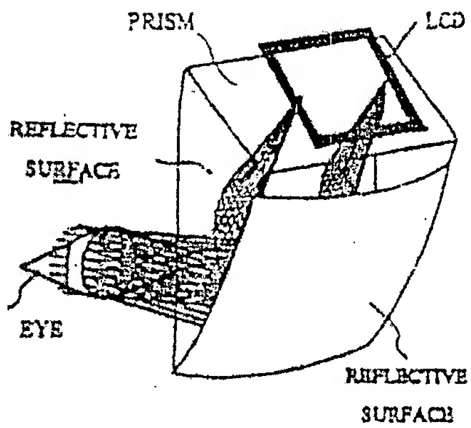


Fig. 9, Closed HMD

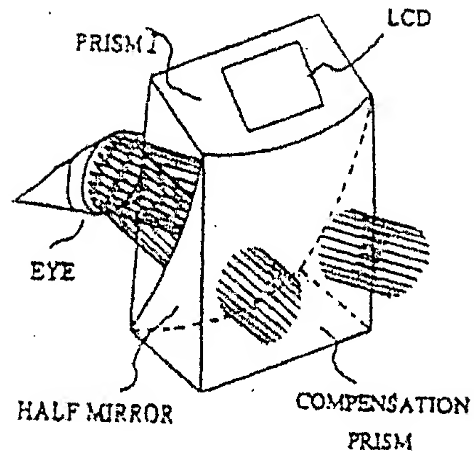
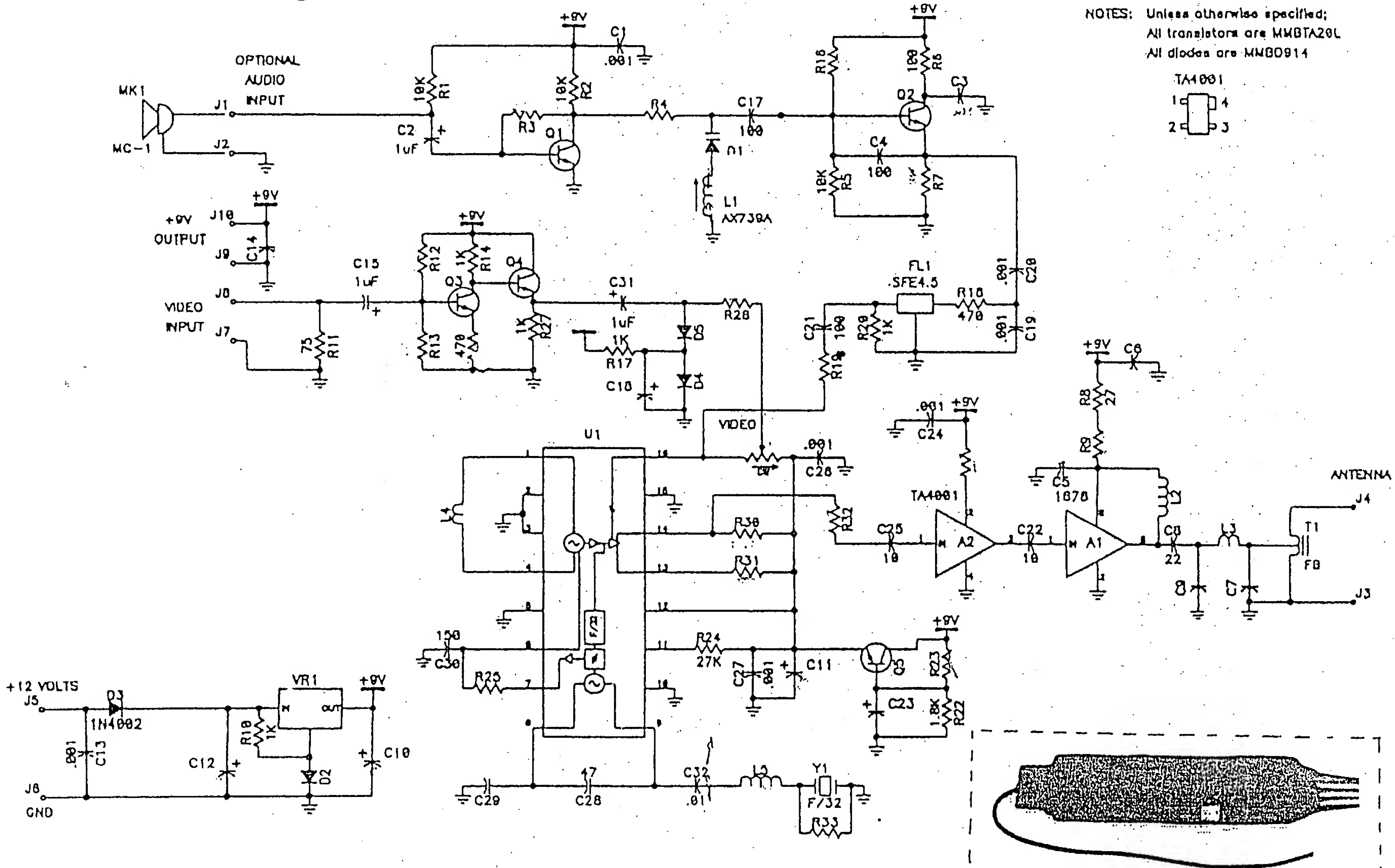


Fig.10, See-through HMD

Fig.11, LLL CCD and IR electronic fusion system;

Schematic Diagram



Actual size

Fig. 1 2 , Wireless Transmitter Schematic Diagram

EXHIBIT C

Fact 5

A00-149 **Development of Universal, Inexpensive Optics for Uncooled Infrared Commercial and Military Applications**

Principal Investigator: Evan Zhang, Ph. D, Zybron, Inc.
Consultants: Tom Milster, Ph. D, Optical Center of Arizona Univ.
F. T. S. Yu, Ph. D, Pennsylvania State Univ.

C. IDENTIFICATION AND SIGNIFICANCE OF THE PROBLEM OR OPPORTUNITY

The rapid development of Uncooled Focal Plane Arrays (UFPA) - BST, PST, VOx Microbolometer (MBT), Si Microbolometer, etc. in recent years had created large commercial and military applications. NETD values as low as 8.6 mK have been measured for Raytheon SB-151 UFPAs with f/1 optics. A 2.3-Oz UFPA Micro camera without using TE cooler had been made by Indigo, Inc. Zybron had produced the helmet mounted camera using BST with best performance (see Fig.1) and the helmet/rifle mounted NIR (LLL CCD or I^2/Gen III) and LIR (microbolometer) combination system taking advantages and overcoming shortcomings of both systems (see Fig.2).

Although the prices of UFPA and electronic board had been reduced 25%, the price of the IR camera is still beyond \$13,000 made by BST and \$17,000 made by MBT. Mainly this is because of using expensive Germanium (Ge) optics. The optics (objective lens, camera window and detector window) almost occupies 30% of the total camera cost. If the UFPA is used for missile or aviation, and extra dome cover lens or window should be added and the optical aperture must be large, in this case the optics will occupy more than 50% of the total camera cost. Besides, making large crystal Ge is difficult and Ge is very sensitive to the temperature change. If the temperature rises to 120° C, it becomes opaque. Therefore, Ge is not suitable for aviation window and missile dome lens. Therefore, universal and inexpensive non-Ge optics for UFPAs is sought.

In addition, different UFPA manufacturers and camera vendors use different diameters, focal lengths, f-numbers and mountings for different optical designs, there is no standard. This further increase the camera cost and inconvenience if the customer wants to change a lens. To have a standardised optics is necessary and possible because the UFPA formats are standard (such as 320x240/50 μ, 160x120/50 μ; 320x240/25 μ, 160x120/25 μ; 640x480/50 μ, 640x480/25 μ). Especially, the mount between the camera and lens can be standard (such as C-mount), then the user can easily change different lenses by himself.

Uncooled detectors are thermal detectors, they have broad wavebands, such as BST is sensitive from 1 μ to 35 μ. Since Ge lens can only be used in 8 – 12 μ, all UFPAs currently are limited in 8 – 12 μ only. If the optical material has a broad waveband (such as from 1 μ to 12 μ), it is possible to build a multi-channel IR camera (such as in three atmospheric windows: 1 - 2.4 μ, 3.3 – 5 μ, and 8 - 12 μ) using one common optical aperture. Three images from 3 wavebands can overlap together. This is an expected but unsolved problem until today. Therefore, to find a non-Ge optical material with broad waveband is also necessary.

The effort of this research is to solve all above problems.

D. PHASE I TECHNICAL OBJECTIVES

The phase-I objectives are to develop a universal optical test bed that will exploit a more conventional approach to optics design coupled with improved detector performance enabling a broad use of the technology in commercial sectors, and providing for the first time a stronger basis for satisfying military requirements. Results of this effort will provide more economical approach to satisfying commercial needs and the Army's mission objectives in the area of infrared sensors.

E. PHASE I WORK PLAN

In order to solve the problems mentioned in paragraph C and reach the objectives listed in paragraph D, innovative but feasible system and subsystems designs are proposed. Following is our solid work plan.

1. New Non-Ge Optical Materials and Their Simple Production Methods

In order to cover three atmospheric windows, the new non-Ge optical materials must have good transmittances from 1.0 μ to 12 μ, and their prices must be much cheaper than crystal Ge. After carefully investigated all existing optical materials, we found that the polycrystals ZnS, ZnSe, their mixed polycrystal $ZnS_{1-x}Se_x$, and infrared glass $Ge_{33}As_{12}Se_{55}$ are the best multi-spectral lens and window materials.

As shown in Fig. 3, polycrystal ZnS has almost flat transmittance of 78% (before anti-reflection thin film is coated on) from 0.8 μ to 12 μ. ZnSe has almost flat transmittance of 75% from 0.7 μ to 20 μ. IR glass has almost flat transmittance of 75% from 0.7 μ to 16 μ. After their anti-reflection thin films are coated on, their transmittances can be over 97%. These materials also have excellent optical, chemical, thermal, and mechanical performances. Their production methods are:

(a) CVD method

The procedure of making ZnSe (as an example) using Chemical Vapor Deposit (CVD) method is to let Zn vapor and H_2Se vapor make a reaction under a temperature greater than 600° C and under a pressure less than 100 Torrs. The resulting reaction can be described as:

$$Zn + H_2Se = ZnSe + H_2\,(\text{gas}) \tag{1}$$

The material ZnSe molecular is then deposited on a graphite substrate to obtain a polycrystal. The size of the polycrystal is about 50 - 100 μ. The growing speed is about 200 μ / hr. Stress can be removed by annealing. By using the CVD method, large size and good optical performance polycrystal ZnSe can be obtained.

However, the CVD method is slow. Therefore, we proposed to use another economic and fast method - "Hot Pressed Method".

(b) Hot pressed method

It is well known that the transmittance of polycrystal is depending on the scattering and absorption of impurities and micro gas holes (air bubbles). The purpose of hot pressing is to use high temperature and high pressure removing impurity and micro gas holes. Therefore the polycrystal will almost become a pure polycrystal. Let us use polycrystal ZnS as an example. Before hot pressing, we put ZnS powder under H_2, H_2S and other inert gases and hit it to 400 - 700 °C, then S and other impurities can be removed. For a pure polycrystal, its transmittance can be expressed as:

$$T = I / I_0 = e^{-\alpha L} \exp\{-C_0 L_v d_v [(n - n_v) / \lambda]^2\} \quad (2)$$

where, I is the intensity of transmitted light, I_0 is the intensity of incident light, α is the absorption coefficient of polycrystal (cm^{-1}), L is the thickness of the polycrystal (cm), C_0 is a constant (usually $C_0 = 7$), L_v is the equivalent thickness of micro gas holes (μ), n is the refraction index of the polycrystal, n_v is the refraction index of the micro gas hole ($n_v \cong 1$), and λ is the wavelength. Eq. (2) represents the effect of micro gas holes to the transmittance of polycrystal. Under high temperature (400 - 700 °C) and high pressure (1,000 - 3,000 kg/cm^2), the micro gas holes will be removed and the surfaces of micro polycrystal particles will contact each other closely, thus high density and very stable hot-pressed polycrystal can be formed. The optical, thermal, and mechanical features of the polycrystal will be almost as same as the pure polycrystal, but the price will be much lower than pure polycrystal.

The hot pressing method was invented in China and the Principal Investigator was one of the researchers in the program before he came to USA.

2. Good Performances of Hot-pressed Polycrystal Materials

Obviously the hot pressing method is more attractive than the CVD method. The question is that how good the performance of polycrystal will be?

Table 1 (referencing Chapter 2 of the Principal Investigator's book "Infrared Optical Engineering") lists the performances of some hot pressed polycrystals. From the table we can see that they have excellent optical, thermal, chemical, and mechanical performances. Let us see ZnS. The thermal expansion coefficient of ZnS is close to most glasses, metals and alloys, thus it can be easily connected with these materials without broken when temperature suddenly changes. ZnS has high melting temperature, thus high environmental temperature (such as if it is used as a missile dome cover lens) will not melt it and seriously affect its transmittance. It has good mechanic performance and is easy to be polished because its hardness is high. It has zero solubility in water, thus it can be exposed in the high-humidity atmosphere even in the water. All these excellent

features make hot-pressed polycrystal ZnS as a good candidate for multi-spectral window and lens from near infrared to long infrared (such as for three atmospheric windows).

Table 1. The Performances of Some Hot-pressed Polycrystals

Name	Band μ	Trans-mittan. For IR 200 –300 μ	Index at 5 μ	Mel-ting Point °C	Densi-ty g/cm³	Hard-ness K	Elastic Coeff. 10^5 kg/ cm²	Therm -al Expan. Coeff. 10^{-6}/°C	Solubi-lity g/into 100 g water	Feature and appli-cations
M_gF_2	0.45 - 9.5	20-48%	1.84	1396	3.18	576	11	11.5	0	good, large window, lens
Z_nS	0.80 – 12	32-40%	2.25	1020	4.09	354	9.7	7.0	0	Same
M_gO	0.40 – 10	49 – 55%	1.7	1100	3.58	640	9.8	13.9	0	Same
C_aF_2	0.20 - 12	4.0 – 23%	1.37	1150	3.18	200	10	10.5	Little	Better than crys-tal, lab use
Z_nS_e	0.70 - 20	1.0-5.0%	2.4	1000	5.27	150	9.8	7.7	0	lens, window, wide band
C_dT_e	2.0 - 30	5.0-15%	2.7	1200	5.85	40	10.5	5.9	0	excellent, soft, lens
L_aF_2	1.0 - 13	7.0-12%	1.5	1450	5.40	610	9.7	7.8	0	excellent, dome lens

The only shortcoming of ZnSe is that the hardness is not as high as ZnS, thus we suggest to produce polycrystal alloy $ZnS_{1-x}Se_x$. This polycrystal alloy will have much higher hardness than ZnSe.

Therefore, hot-pressed polycrystals ZnS, ZnSe and $ZnS_{1-x}Se_x$ will be good multi-spectral lens and window materials from NIR to LIR.

3. Simple Procedure of Making Lens and Window

To make the lens and window using crystal Ge, we must grow the single crystal slowly, then carefully cut the crystal, ground the crystal, and polish the crystal. A large amount of labor is involved. It makes the lens and window very expensive. For hot-pressed crystals, we only need their powders. The polycrystal powders can be easily hot pressed into specific lens and window shapes and thickness. The hot pressed lens and window then can be grounded and polished. Significantly less labor is involved. Since the methodology of producing a hot pressed polycrystal lens and window is straight forward, the mass production is relatively simple. Therefore, the cost of the lens or window made by hot-pressed polycrystals will be only 20-30% of that made by crystal Ge. Since to

grow large size crystal Ge is very difficult and even impossible if the size is too big, thus the sizes of Ge lens and window are limited. However, polycrystal ZnS powder can be easily hot pressed in different sizes and shapes for lens and window. The diameter can be over 500 mm. Therefore, it is possible to build an inexpensive large missile dome lens or aviation window. The hot-pressed polycrystal L_aF_2 is specially suitable for large dome cover lens because it has high melting point, good hardness and zero water solubility.

Not only the cost reduction, there are other advantages of using polycrystal Z_nS, ZnSe and $ZnS_{1-x}Se_x$: (1) the transmitting wavelength of them in the NIR is much better than Ge, thus it can be used for near infrared, (2) the refraction index of them is much lower than Ge; this allows the formulation of a much simpler anti-reflection coating, (3) the transmittances of them in LIR is much higher than Ge, thus more target radiation can be collected by the sensor, and (4) the transmittance of them is only slightly effected by the temperature changing, but Ge is seriously effected and even becomes opaque when the temperature rises to 120° C.

We believe that by using these polycrystal materials, not only the costs of the optical lens and window can be reduced dramatically, but also the performances of the optical lens and window can be increased significantly. For example, they can cover three atmospheric windows from 1 μ to 12 μ, but Ge can not do.

4. Anti-reflection Coating Design

Although the refraction index of ZnS (n = 2.25) is much lower than Ge (n = 4), It still needs an anti-reflection coating. See chapter 3 of Principal Investor's book, the thin film materials for anti-reflection coating can be chosen by following equation:

$$n_0/n_1=n_1/n_2=n_3/n_4=\cdots\cdots=n_{m-1}/n_m \qquad (3)$$

where, n_0 is the refraction index of the air; n_1, n_2, ····· n_{m-1} are refraction indices of coating materials; n_m is the refraction index of the lens and window material.

Because the refraction index of hot pressed polycrystal ZnS is almost half of Ge, the coating is easy to be designed. If n_0=1 and n_3=2.25 (ZnS), from Equation (3) we can see that the following materials are suitable for anti-reflection coating: S_rF_2 (n_1=1.40), and P_bF_2 (n_2=1.65). Therefore the structure of the anti-reflection coating will be

$$\text{Air} / S_rF_2 / P_bF_2 / \text{ZnS} \qquad (4)$$

The big advantage of using Z_nS and ZnSe to make lens and window is that these materials will automatically cut off the visible light shorter than 0.8 μ and IR radiation longer than 12 μ. Therefore, the short wavelength cut-off filter and long wavelength cut-off filter are not necessary to use for three atmospheric windows. A single window will be good enough for all three wavebands.

5. Objective Lens Design

Currently, we have contracts with the Air Force and SOF to develop the UFPA IR camera and NIR & LIR combination system. The imager needs an objective lens in the 8-12 μ having large Field Of View (FOV) 30° x 40° for uncooled Focal Plane Array (FPA) Micro Bolometer or BST with a format of 320 x 240 /50 μ. Because the sensitivity of uncooled FPA is lower than cooled FPA, to increase the signal to noise ratio, fast optics f/1 is requested, and its Modulation Transfer Function (MTF) must be over 70% on the axis and over 50% off the axis. Table 2 is the lens feature requirements given by Texas Instruments, Inc. To design this kind high performance lens is very difficult; usually 3 pieces of crystal Ge are needed to make the objective lens. However, as mentioned before, the Ge lens is expensive and will turn to opaque if the temperature increases to 120° C.

In order to overcome the above problems, by using the automatic optical system design software developed by the Principal Investigator, as shown in Fig.4, an objective lens using above polycrystals is successfully designed. The new lens not only satisfies all requirements listed in Table 2, but also reduces the price to 1/2 of the Ge lens.

Table 2. Objective Lens Feature Requirement

Materials	Polycrystals: ZnSe (n = 2.4053 at 10 μ); ZnS (n = 2.1900 at 10 μ). IR glass: $Ge_{33}As_{12}Se_{55}$ (n = 2.4977 at 10 μ).
Effective focal length	0.90 inches (22.86 mm)
F/no.	1.0 desired, 1.2 required
Diameter	0.9" (22.86 mm), 0.75" (19.05 mm)
Field of view	30° x 40°
Image format height	0.468 inches (11.89 mm); 245 pixels, 48.5 μ/pixel
Image format width	0.626 inches (15.90 mm); 328 pixels, 48.5 μ/pixel
Instantaneous FOV	0.122° x 0.122° (30 °/245 x 40°/328)
MTF @ fo	70% on axis (fo = 10 lp/mm or =.23 cy/mr) and 50% Off axis, for infinity target
Instantaneous depth of field	2 feet to infinity desired, 4 feet to infinity required
Spectral band	1.0-13.5 microns desired, 8 - 12 μ required
Maximum number of lens	3 pieces, spherical
Maximum lens diameter	1.15 inches (including the wandering of pupil)

Back working distance	minimum 8 mm from the last surface of the lens
Detector window	n = 3.42, thickness 0.635 mm, distance from back surface to detector 1.04 mm.
Average transmittance over spectral band after coating	85%
Minimum transmittance in spectral band	75%
Coating material	Non-thoriated
Environmental coating	Outer surface of outer lens
Athermalization	MTF requirement met for ambient air temperature range of -20° C to + 55° C

Based on this successful design, we also have designed a series of non-Ge objective lenses with different focal lengths (from 8.5 mm to 100 mm), different f-numbers (from f/1.0 to f/2.0), different FOV (from 10.5°x14° to 43.5°x58°), and different back working distance (from 6.8 mm to 18.8 mm) to fully fit all existing UFPAs.

Every lens has a male C-mount, thus the user can change different lenses quickly if the camera body also has a female C-mount interface. Currently all UFPA cameras did not use C-mount. To change the lens is very complicated.

6. Common-aperture Multi-channel IR Camera Design

Since the new objective lens has a broad waveband from 1 μ to 12 μ, we should fully use its performance. This is the first time in the history that an IR camera covering 3 atmospheric windows is designed. In order to let images on three FPAs corresponding to three wavebands have good alignment, we must use a common optical aperture to receive the incident infrared radiation from the target then we can split it into three channels. As shown in Figure 5, immediately behind the objective lens L_1, a beam splitter filter F_1 is inserted to reflect the NIR of 1 – 2.4 μ to the first FPA, and pass the MIR and LIR radiation. Then a second beam splitter filter F_2 is inserted to reflect the MIR of 3.3 – 5 μ to the second FPA, and pass the LIR of 8 – 12 μ to the third FPA. These three FPAs can be three BST UFPAs. Now the NIR, MIR and LIR images can be overlapped together precisely because they have same material and same size of FPAs. From these images we can get more information from the target for correct discrimination. If narrow band filters are used, we can further divide these three channels into many sub-channels. This is the dream that military wishes to realise long time ago.

In the past, we must use infrared glass lens for NIR, crystal Si lens for MIR, and crystal Ge lens for LIR individually; the system is bulky, expensive and can not overlap three images together. Now, by using our innovative lens design, all above shortcomings are overcome.

7. The Consideration of Plastics

Plastics are cheap and easy to be molded in different shapes. In addition, they have zero solubility in water, acid and alkali. However, they are not hard enough and have relatively low melting points. In addition, their transmittances in three atmospheric windows are not flat and relatively low. Therefore, they are not suitable for missile dome cover lens or aviation window. However, if the environmental temperature is not high and stable, they probably can be used as lens and window materials for UFPAs. For example, plastic TPX has good transmittance in the visible and infrared. It has low reflection index (n=1.43); thus anti-reflection is not necessary to use. When the optical system is calibrated in the visible (it is easy to do), it can be used in infrared without re-calibration because its refraction index does not change with wavelength. The designing method of plastic lens is similar to glass lens. Several plastic lenses and windows have been designed by using the automatic lens design software developed by the Principal Investigator.

8. Items To Be Delivered

After finishing the proposed 6-month research, following items will be delivered to the sponsor:

(1) A program based on a set of general skew ray tracing formulas developed by the Principal Investigator.

These formulas are very useful, because they are analytic and can treat any spherical and aspherical, coaxial and non-coaxial, tilted and non-tilted optical systems.

(2) An automatic lens design software with detailed instruction.

We not only will give the software to the sponsor in C language, but also will give the source code and detailed instruction to let the sponsor modify the program by himself. Usually no company will give the source code to others. By using this software, the user can design the lenses by himself.

(3) Design any lens or window specified by the sponsor and use polycrystals to make the lens or window for any UFPA sensors.

(4) Design a common-aperture non-Ge objective lens for three atmospheric windows.

(5) If sponsor is interested in the hot pressing method to make the polycrystals, we can negotiate with China to purchase the equipment from China, because the hot pressing method was invented in China. If extra fund is available, we also can build up the equipment for sponsor by ourselves. The Principal Investigator has enough knowledge in this area.

8. Statement of Work and Schedule

The following is a step-by-step approach to the effort that will allow us to select a defined approach to the problem and to determine the feasibility of the selected system:

Task 1. Overall System Design
----- two months

- Applications of multi-spectral lens and window for sensors
- Performance requirement
- General design and manufacture consideration
- Lens and window cost analysis

Task 2. Consideration of Material Manufacturing Method
----- Two months

- Polycrystal material selection
- Hot-pressed Method
- CVD method
- Material performance measurement

Task 3. Non-Ge Objective Lens and Window Design and Fabrication
----- Three months

- Detailed lens and window performance requirement
- Material consideration
- Software development
- Lens design and fabrication
- Window design and fabrication
- Performance testing

Task 4. Anti-reflection Coating Design
----- Two month

- Theoretical analysis
- Coating material selection
- Anti-reflection coating design and manufacture
- Measurement

Task 5. Common-aperture Three-channel IR Camera Design
----- Two month

- Theoretical analysis
- Common-aperture lens design
- Three-channel IR camera design
- Experiment and measurement

Task 6. Final Report
----- One month

- Detailed design, drawing, and analysis
- Program and software delivery
- Non-Ge lens and window delivery
- Common-aperture three-channel IR camera design delivery
- Detailed experiment and measurement results

The schedule for the above tasks is shown in Table 3.

Table 3. Schedule of Tasks

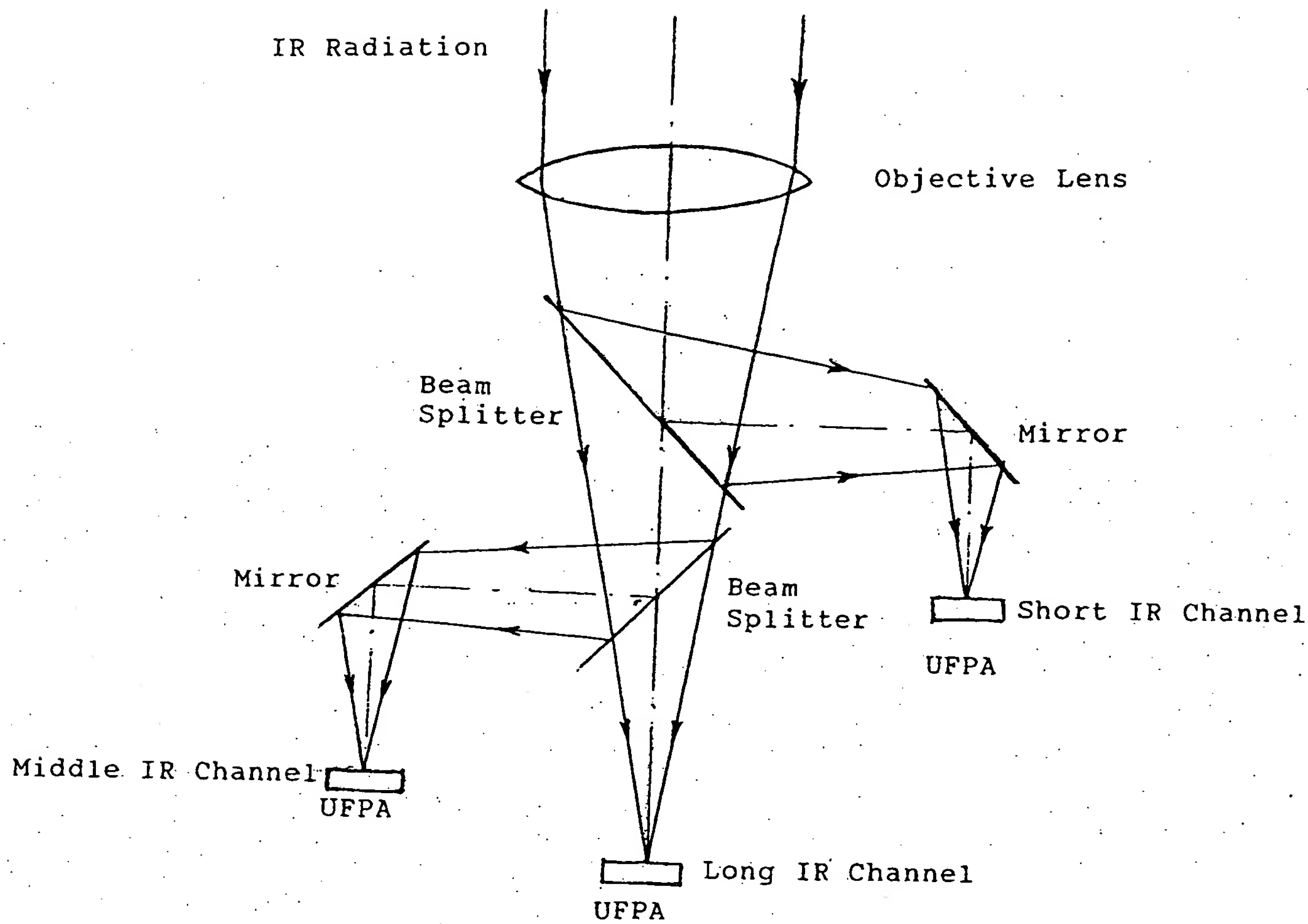
```
                         Month from contract awarded

Tasks     0        1        2        3        4        5        6        7

Task 1    Λ------------------Λ
Task 2             Λ------------------Λ
Task 3                      Λ---------------------------Λ
Task 4                                Λ------------------Λ
Task 5                                     Λ------------------Λ
Task 6                                                        Λ--------Λ
```

F. RELATED WORK

Zybron, Inc. is a high technology minority firm [8(a)] founded in 1988 to conduct research in the optical/electronics arena. Zybron had gotten 3 Phase-I and 3 Phase-II SBIR awards from the United States Air Force and achieved 3 breakthroughs in the areas of optical recording and LIR imaging: (1) produced a low cost light weight holographic lens for re-writable optical disk head, (2) produced a multi-channel high speed fiber optic data transfer system for communication, and (3) produced a helmet mounted LIR system without parallax for fire fighting. US Air Force had released special news for Zybron, and many newspapers and TV stations had reported Zybron's successful story. Zybron also had gotten 2 phase-I contracts from the Special Operations Forces in 2,000. Two prototypes: NIR & LIR combination system using non-Ge common-aperture objective lens and assault zone mark using special LEDs have been built up for these contracts.



To sensor fusion board for electronic fusion
or to eye piece for optical fusion

Fig. 5, Unique IR imaging system design using common optical aperture and same detector array to cover whole IR spectra from short IR to long IR

Scientific base of the design:

(1) Our objective lens made by $(ZnSe)_x(ZnS)_{1-x}$ + AMTIR-1 has good transmittance from 1 μ to 12 μ.

(2) Uncooled Focal Plane Array (UFPA) is sensitive from 1 μ to 12 μ.

(3) Because of the common aperture, 3 UFPAs can be aligned perfectly, thus precise image processing (such as subtraction) can be performed.

(4) This 3 channel system can be further developed to a multi-spectral/hyper-spectral imaging system covering SIR to LIR.

Fact 6 Sensor Suite for UAV

First, we will design a common optical aperture to fuse the VIS, LIR and Ladar images pixel by pixel in real time, then we will design an electronic board to combine this fused image with the Radar image and display them picture in picture on a small LCD. Therefore, we are able to get the signatures of all above sensors simultaneously for easy target identification.

It is well known that the CCD camera has high-resolution but no thermal signature. On the other hand, the LIR imager can detect the target heat but the resolution is limited. The best way is to fuse them together. However, a focal-plane-array (FPA) sandwich between VIS and LIR is currently not available, and no real-time pixel-by-pixel EO/CCD and LIR sensor fusion system exist. To address this void, Zybron has patented an innovative VIS-LIR pixel-by-pixel sensor fusion design. The proposed sensor fusion design exploits the advantages offered by both sensors while overcoming the shortcomings of each sensor. The fused sensors have the ability to acquire images equally effective during the day or nighttime because the LIR sensor can see through darkness, thin fog/cloud, smoke, dust, tree canopy, and camouflage cover and give the IR signature while the EO/CCD sensor can provide high resolution features such as colors, detailed shapes, and textures.

To perform pixel-by-pixel sensor fusion in real time, a common optical aperture is needed. We have designed and patented three common optical apertures for VIS and LIR sensors: common refractive objective lens using poly-crystals ZnS and ZnSe, common reflective objective lens using two mirrors, and common beam splitter using thin film. By considering the alignment difficult, the large field of view (FOV) and low cost requirements, and other factors, here we only choose the common beam splitter approach for the UAV sensor fusion suite. Fig. 1 shows the EO/CCD, LIR and Ladar sensor fusion approach. The common beam splitter BS_1 will pass LIR from 8 to12 μ and reflect VIS/NIR from 0.38 to 0.95 μ. The LIR will be imaged on the uncooled FPA (UFPA) by lens L_1 made by LIR materials. Since the UFPA format is different from CCD, before sending the image to the Image Fusion Board (IFB), the IR image data needs to be fed to a reformation circuit board (RCB) that will fill in data between pixels and scale the pixel to match the CCD image resolution and format in real time (as an evidence see Fig. 9). In the future if we let the CCD and LIR have equivalent objective lens and FPA, the RCB is not necessary to use.

The IFB would allow us to send a fused image (addition, subtraction, etc.) from two sensors to the UAV computer for pre-processing in real time then wirelessly send to the ground computer for further processing and display the result on the LCD for more efficient and accurate target identification because the fused image has signatures from both sensors and the computer can compare the information from the database for automatic IFF. **To detect biological and chemical weapons,** we can put a filter F_{IR} (a rotating disk with one 8-12 μ band and N sub-bands) in the front of UFPA and a filter F_{VS} in the front of CCD.

In this proposal, we also plan to incorporate a laser range finder, where the laser at 1.06 μ, 1.55 μ (eye safe) or other wavelengths beyond 1 μ and less than 8 μ will hit the target through beam splitter BS_3 (half mirror), mirror M_1, beam splitter BS_2 (passing laser beam and reflecting VIS), and beam splitter BS_1. The return beam will be reflected by beam splitter BS_3 and mirror M_3, and goes to the detector D. The signal will also be displayed on the LCD under the fused EO/LIR image as a footprint to indicate the distance and location by cooperating a compass with the laser. Because the laser can measure the distance and the

compass can determine the angle so the GPS coordinate of the target can be obtained even if the target is not directly under the UAV (if we use laser to measure the angle, the compass is not necessary to use). An electronic cross-hair will be created on the LCD to show the optical axis and also the laser beam on the target. By continuously measure the GPS coordinates of the moving target, we are able to know the velocity and direction of the moving target. This unique and innovative approach will enable the operator at the strike-platform or the ground control center to see, aim, and trace the target by properly operating the UAV and locking the laser on the interesting moving target.

For active laser imaging systems, either a continuous or a pulsed laser is used. If height information is required, a pulsed laser must be used. The narrow, pulsed beam is scanned along the x-direction, usually with a rotating mirror assembly M_1. A second mirror in the scanning assembly collects the return signal and reflects it into a single detector, usually a photo-multiplier tube. The forward motion of the UAV platform yields the y-axis information for subsequent scans. In this way a two dimensional image can be constructed. For a pulsed laser system, the height information is obtained by measuring the time between the launch of the laser pulse and the return signal. This time Δt of flight of the laser pulse corresponds to twice the distance h from the Ladar to surface of reflection; i.e., $2h = c\Delta t$, where c is the speed of light in air. The height information can be obtained on a pixel-by-pixel basis throughout the scan and a three-dimensional (3-D) map of the surface can be constructed. The vertical resolution is about 15 cm if a photo-multiplier tube is used. If an avalanche photodiode is used, the vertical resolution will be about 4.5 cm.

If a continuous laser source is used, we also can get a 2-D map. The beam is expanded in one direction, by means of a cylindrical lens, so it looks like a fan. The detector is a one-dimensional diode array (or CCD). This system does not require scanning; the diode array detects the laser return providing the x-axis information while the forward motion of the platform gives the y-axis for subsequent readouts of the array. In this way a two-dimensional image of intensity versus x-y position can be constructed. Used in this way, beam fanning does not provide surface depth, or surface structure information. However, if a two dimensional CCD is used, instead of a linear array, and there is a separation d, between the source and receiver, then surface structure can be obtained. The accuracy (resolution) with which h can be measured will depend on the accuracy that the source-receiver separation and the angles are known.

The key innovation of this approach is the common aperture for CCD, LIR and Ladar three sensors that eliminates the need for further software-based alignment and rotation for registration of images produced by three different apertures (sensors). The other key innovation is the pixel-by-pixel fusion ability that will present a sensible image from three sensors under any operating conditions in real time. The fused image will be wirelessly sent to the strike platform or ground station for further image processing using bigger computer, powerful software, and larger database for correct IFF. If needed, the three images can also be displayed separately in various forms of picture-in-picture presentations.

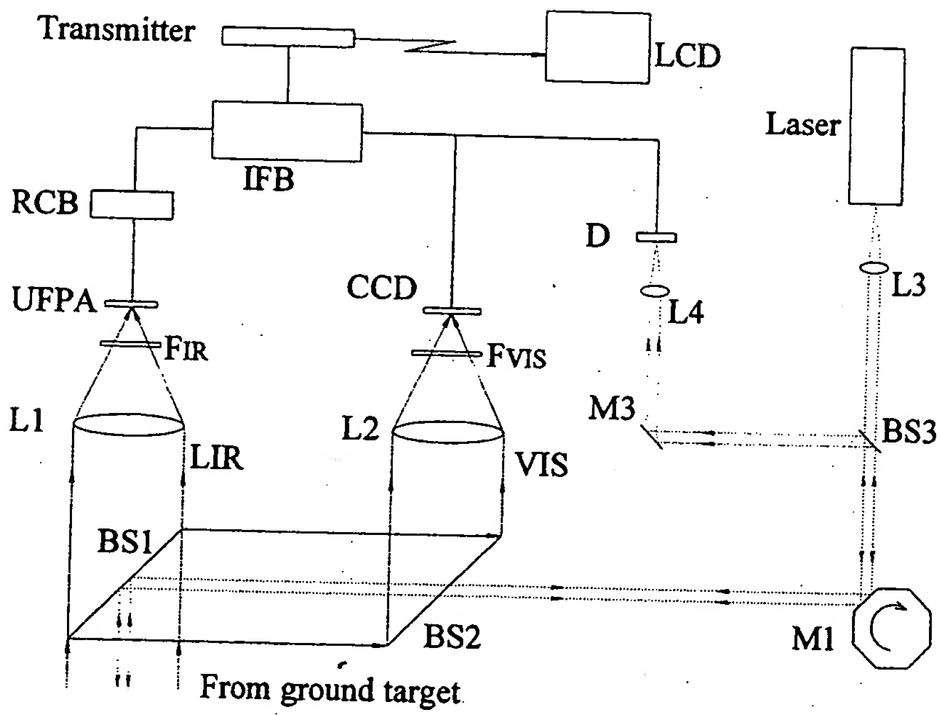


Fig. 1, LR, CCD, and Ladar sensor fusion using a common beam splitter

However, Radar is not an optical sensor, we cannot use above common optical aperture to fuse it with above optical sensors. In order to solve this problem, as shown in Fig. 2, an electronic sensor combination board (SCB) is designed. The input of the main channel is the fused image from VIS, LIR and Ladar. The input of the sub-channel is the Radar image. The chips are commercial available. The difference between IFB and SCB is that the images sending to the IFB are from the same aperture and preprocessed to have the same format, but the images sending to the SCB are from different apertures and do not have the same format. Therefore, the SCB can only display the combined images picture in picture not pixel by pixel on a small LCD. However, this system is a hardware-based not software-based system with a speed almost in real time, so it is useful and suitable for pre-processing on UAV and for quick human analysis at ground station if wirelessly sent the image from UAV to LCD.

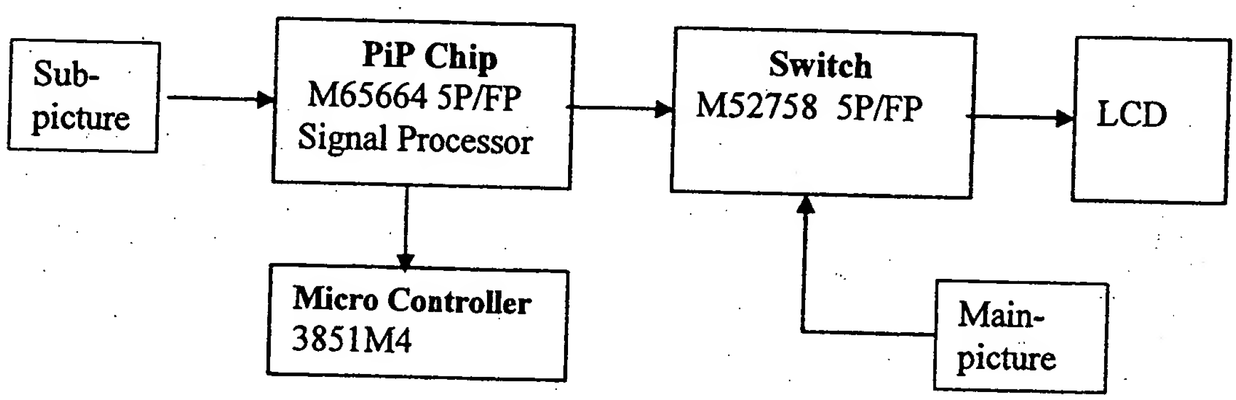


Fig. 2, The block diagram of the Picture-in-Picture circuit board

As a demonstration, Fig. 3 shows a picture in picture image display which is wirelessly sent from CCD and LIR to a small LCD (PiP is only existing for big TV not for small LCD).

EXHIBIT E

Fact 7

Phase I Small Business Innovation Research (SBIR) Program

Proposal Cover Sheet

Proposal Number: N012-0145 Agency: NAVY
Topic Number: N01-179
Proposal Title: Low-Cost Dual-Mode (Visible/Infrared) Imager
Firm Name: ZYBRON INC. Optical Electronics
Mail Address: 3915 Germany Lane

Beavercreek, OH 45431-1608

Web Address:

Proposed Cost: 69959 Phase: I Duration: 6
Option Cost: 29928 Option Duration: 3

BUSINESS CERTIFICATION:

Are you a small business as defined in paragraph 2.2?	YES
Number of employees including all affiliates (average for preceding 12 months):	18
Are you a socially or economically disadvantaged business as defined in paragraph 2.3?	YES
Are you a woman-owned small business as described in paragraph 2.4?	NO
Has this proposal been submitted to other US government agencies, or DoD components or other SBIR activity?	NO
If yes, list the name(s) of the agency, DoD component or other SBIR office and Topic Number in the space below.	
Is your company (either directly or as a subcontractor) performing work for a Navy activity outside of SBIR or STTR funded work?	NO.
If so, please indicate the organization and the specific code in which this work is performed in the space below.	

Project Manager/Principal Investigator		Corporate Official (Business)	
Name:	Dr. Evan Zhang	Name:	Dr. Ronald L. Fletcher
Title:	Research Director	Title:	V. P.
Phone:	(937) 427-2892 EXT 10	Phone:	(937) 427-2892 EXT 20
Fax:	(937) 427-3252	Fax:	(937) 427-3252
E-Mail:	Evan_Zybron@Ameritech.net	E-Mail:	rfletcher@zybron.com

For any purpose other than to evaluate the proposal, the data referenced below shall not be disclosed outside the Government and shall not be duplicated, used or disclosed in whole or in part, provided that if a contract is awarded to this proposer as a result of or in connection with the submission of this data, the Government shall have the right to duplicate, use or disclose the data to the extent provided in the funding agreement. This restriction does not limit the Government's right to use information contained in the data if it is obtained from another source without restriction. The data subject to this restriction is contained on the pages of the proposal listed on the line below.

Proprietary Information:

[signature]	8/2/01	Dr. [signature]	8-2-01
Signature of Principal Investigator	Date	Signature of Corporate Business Official	Date

Technical Abstract (Limit your abstract to 200 words with no classified or proprietary information/data.)

In order to overcome the short distance (it is critical for seeker) and high cost problems of the dual-mode imager using UFPA and fully meet the task requirement, very innovative ideas and designs are proposed: 1. By using a smaller UFPA format of 240x320/25 u and adding an immersed detector lens on it, the detection distance can be increased 8 times. 2. By designing a 150-mm and F/1 objective lens with non-Ge materials and using its simple production method, the price can be reduced to 1/3 of the Ge lens. 3. By using two heads and a video switch to let the VS and IR share time alternatively on the LCD, we are able to combine the VS and IR images together without blurring the overlapped image. 4. In order to eliminate the parallax between VS and IR for pixel by pixel image fusion and autonomous target recognition, three common optical apertures: common refractive objective lens, common reflective objective lens, and common beam splitter are designed. The common refractive objective lens uses ZnSe as the common front lens then uses normal glass for VS and IR glass for IR to correct their aberrations in VS (0.5-0.9 u) and IR (8-12 u), thus we don't need to correct aberrations in the whole band from 0.5 to 12 u. Without this innovative idea, it is impossible to design a lens for both sensors. 5. All existing UFPA imagers use traditional electronic circuit design with Thermal Electrical Cooler, thus the volume is big, the power consumption is large and the cost is high. Our new design only uses one Altera chip for all digital signal processing and does not use TEC. Therefore, a 3.5 OZ Si-bolometer IR imager (excluding lens) with 240x320/25 u resolution can be produced. Two 1.2 V Lithium "AAA" batteries can power the imager for half-hour. It will be long enough for seeker during its flying. 6. By using above innovative designs, the total volume of the dual-mode imager will be less than 7-cube, the weight will be less than 1.2 Lb, the resolution will be better than 0.25 mrd, the NETD will be less than 0.9 degree C, and the price will be less than $10 k. The imager will have RS-170 output, digitized imagery, signal interface, simultaneous display/processing, and electronic zooming. 7. We will deliver a dual-mode VS/IR imager prototype for seeker to Navy and conduct the lab and field testing. We also will give detailed optic, electronic and system designs and drawings to Navy.

Anticipated Benefits/Potential Commercial Applications of the Research or Development.

The proposed dual-mode imager not only will give great help to Navy for the development of new seeker, but also will greatly assist government agencies to detect and identify suspicious subjects without prompting flight or confrontation in a variety of environments (darkened buildings, jails, alleys, night scenes, smoke, dust, and other adverse weather conditions). Not only fire fighting, anti-terrorist, building security, and hunting, but also most squad cars and police helicopters would require this type of system. In most applications, the visible is used for daytime or artificially lit scenes and the infrared for smoggy or nighttime conditions. Under many daytime conditions, the visible and infrared images can be correlated with each other to maximize the information gathered. Maxtech International, Inc. has predicted that the US market for this type of imaging system will exceed 1.3 billion dollars by 2003.

List a maximum of 8 Key Words that describe the Project.

Dual-mode imager, Visible sensor, Non-Ge objective lens, Common optical aperture, Infrared sensor, Seeker, Security system, Sensor fusion.

VIS: Low light CCD
Volume: 6.5" x 3.5" x 2.5"
Power: 3.6W, 5 VDC
Transmitter: 0.1"x0.4"x1.5", 0.7 kM range

LIR: Si-UFPA, 160x120/50u
Weigh: 1.52Lb total
Battery: Rechargeable, 4 Hrs
Display: Picture in picture

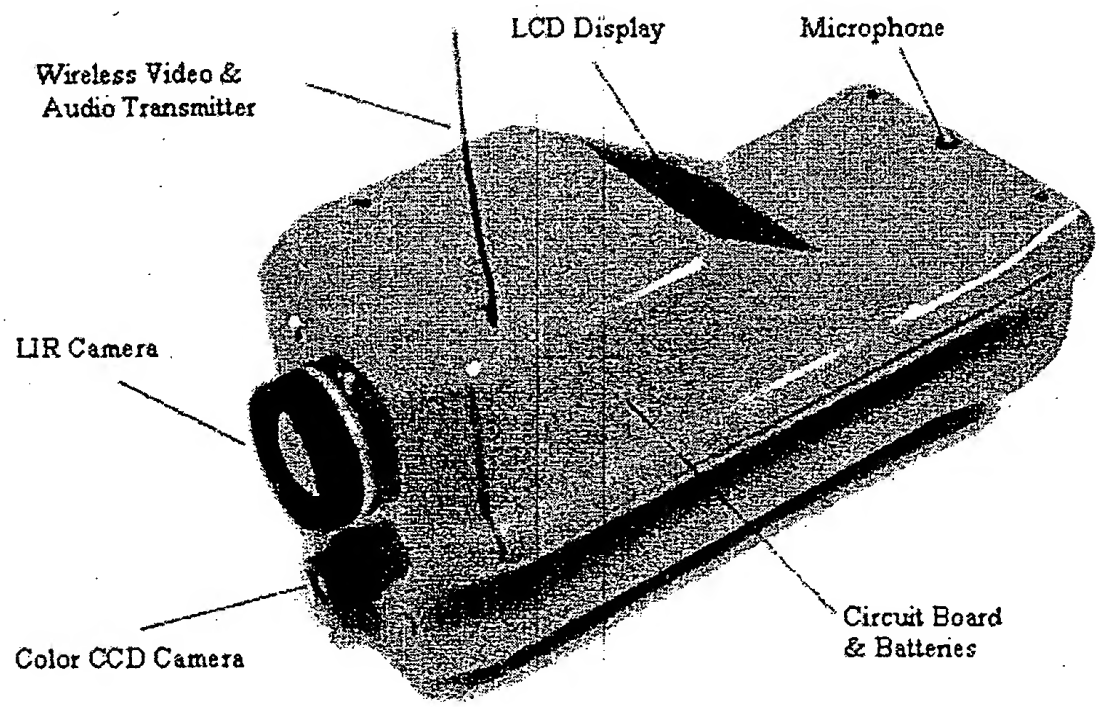


Fig. 3, Hand-held visible and long infrared image fusion system

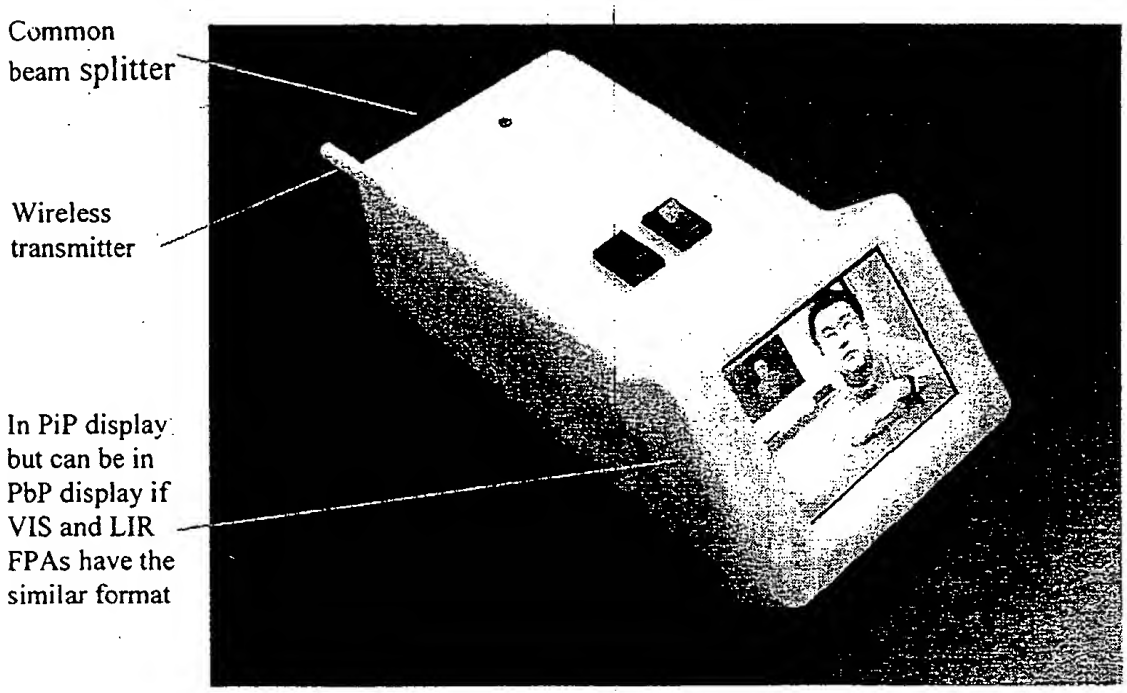


Fig. 4, Handheld VIS and LIR sensor fusion system with common beam splitter

EXHIBIT F

A letter Sent on 28, July, 2000

Dear Army SBIR Office:
For our proposal submitted under topic A00-047, based on our previous work of optical fusion sight with visible CCD and near infrared image intensifier (I^2) using common optical aperture mentioned in our proposal, as shown in Figs 1 and 2, a VIS/NIR and LWIR optical fusion sight for rifle is further developed in this month using common refractive objective lens designed in 1999-2000. This fusion system will more closely address your topic and we can give you a demo in phase-I. If you can attach this document on our proposal it will be appreciated.

Evan Zhang, Ph. D., 7/28/00, Zybron, Inc.

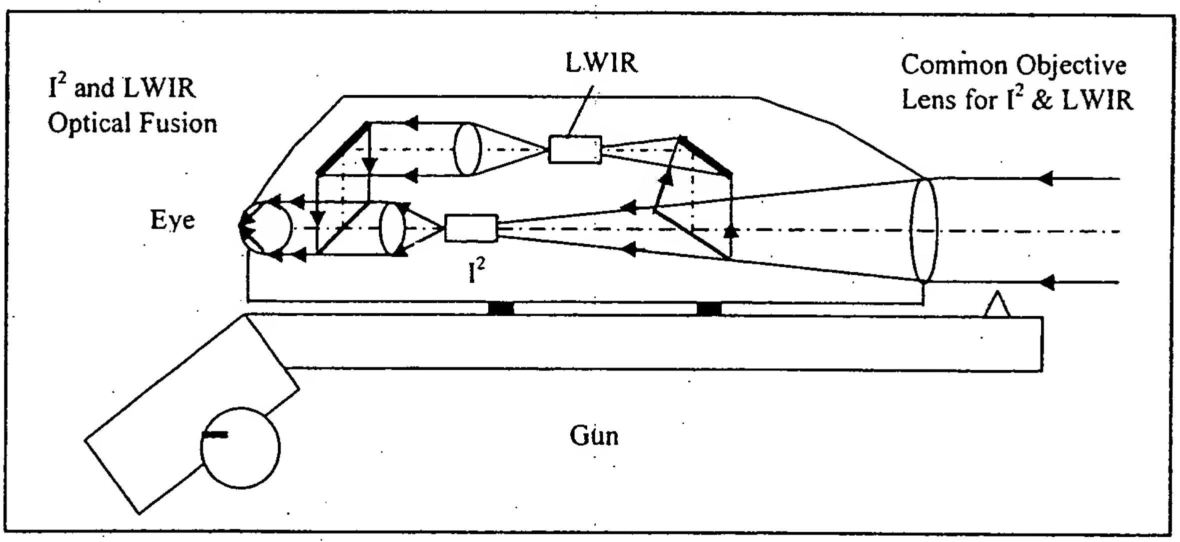


Fig. 1, Gun sight design with VIS/NIR and LWIR optical sensor fusion

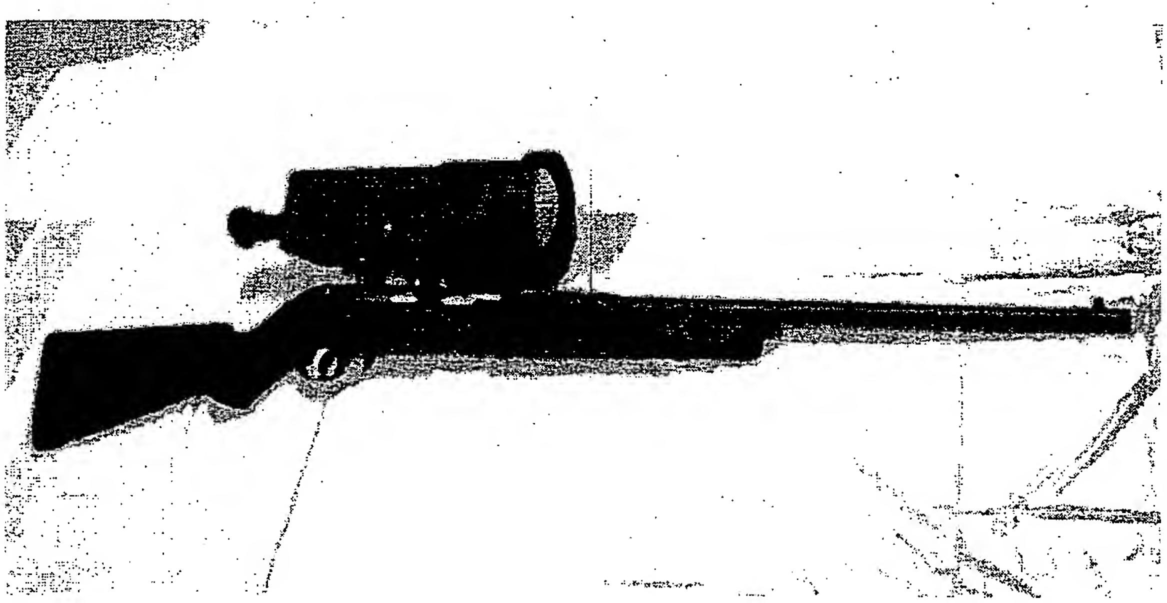


Fig. 2, Gun sight prototype for the design of Fig. 1